Report No. CG-W-01-86

FT MADISON BRIDGE STUDY

D.E. DICKEY

R.K. GRESS

AD-A168 320

MARCH 1986

Prepared for:

U.S. Department of Transportation
United States Coast Guard

Office of Research and Development
Washington, D.C. 20593

NOTICE

This document is disseminated under the sponsorship of the Department of Transportation in the interest of information exchange. The United States Government assumes no liability for its contents or use thereof.

The contents of this report do not necessarily reflect the official view or policy of the Coast Guard; and they do not constitute a standard, specification, or regulation.

This report, or portions thereof may not be used for advertising or sales promotion purposes. Citation of trade names and manufacturers does not constitute endorsement or approval of such products.

1. Report No. CG-W-01-86	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Ft. Madison Bridge Study - Effects of Current, Horsepower and Alternate Channel Configuration on Navigation through the Atchison-Topeka and SantaFe R.R. and Highway Bridge, Ft. Madison, Iowa		5. Report Date March 1986
		6. Performing Organization Code
7. Author's, Dean E. Dickey and Ron K. Gress		8. Performing Organization Report No. 86-01
9. Performing Organization Name and Address Systems Branch (G-WP-2) U. S. Coast Guard Headquarters 2100 Second St., S.W. Washington, D.C. 20593		10. Work Unit No. (TRAIS)
		11. Contract or Grant No. N/A
12. Sponsoring Agency Name and Address U. S. Coast Guard 2100 Second St., S.W. Washington, D.C. 20593		13. Type of Report and Period Covered Technical Report June 1985 – February 1986
		14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

This report is a project summary describing the preparation and conduct of a simulator experiment in River Tow Navigation through the Atchison Topeka and Santa Fe R.R. Bridge at Fort Madison, Iowa using the Coast Guard Maneuvering Simulator. Detailed qualitative and quantitative results obtained from the simulations are presented and analyzed. The study was designed to determine the effects of different levels of current, horsepower, and alternate channel design as well as pilot performance on safety at the bridge. This study was initiated by the Second Coast Guard District due to concern because of number of accidents at the Ft. Madison Bridge. Conclusions of the study include (1) The Fort Madison Bridge does pose an unacceptable risk to experienced pilots; (2) High flow and design of the channel have a major impact on operational safety of navigation span opening of the bridge is inadequate (region

17. Key Words Simulation, Mississippi River, Ft. Madison, River Tows, Safety.	Bridges River Channel, Collisions, Rammings& Groundings, Western Rivers Navigation	18. Distribution Statement		
19. Security Classif. (of this report) UNCLASSIFIED	20. Security Classif. (of this page) UNCLASSIFIED		21. No. of Pages 100	22. Price

Form DOT F 1700.7 (8-72)   Reproduction of completed page authorized

Table of Contents

3

1.0 Introduction

1.1 Background: River tow accidents at or near some bridges on the Mississippi River have become a concern to the Coast Guard, the River Industry and the General Public. The possible consequences of a serious ship-bridge collision can be extremely severe, causing economic loss in the hundreds of thousands of dollars, environmental damage and loss of life. Some barges carry gasoline, fuel oil and other hazardous chemicals such as liquid chlorine which pose a significant threat of fire, contamination of drinking water and toxic gases to the thousands who live near our waterways.

In an effort to improve the level of safety of push tow operations on the Upper Mississippi River, the Second Coast Guard District identified six bridges that have been sites of numerous ship bridge collisions and requested a study of these bridges be conducted using the Coast Guard Maneuvering Simulator, located at the Coast Guard Headquarters in Washington, DC.

The purpose of the study is to systematically analyze conditions (e.g. environmental, type/size of Tow) under which ship bridge collisions occur in order to determine what factors contribute most to reduced safety and identify possible steps that may be taken to increase the level of safety. A secondary purpose is to evaluate the maneuvering simulator's capabilities as a research tool and training aid.

The first bridge studied was the Acthison-Topeka and Santa Fe Railroad Bridge at Ft. Madison Iowa.

2.0 BRIDGE AND CHANNEL CHARACTERISTIC

2.1 Bridge - The Atchison, Topeka and Santa Fe Railway & Highway bridge* crosses the Mississippi at mile 384 between East Fort Madison, Illinois and Fort Madison, Iowa. Bridge characteristics are shown in figures 2.1., 2.2. and appendix A.

Figure 2.1

"Ft. Madison Bridge Characteristics"

Built - July 1928

Type - Highway/Railroad Swing Bridge

Length - 3346' 6"

Horizontal Clearance - 200' (Between Piers)

Vertical Clearance Highwater (closed) - 6.0'

Vertical Clearance Normal Condition (closed) - 12' 8"

Marine traffic passage - North West end of bridge (Ft. Madison side) between

Pier 15 and 14 and between 13 and 14 (North to South Passage - Between

Pier 15 and Pier 14)

Bridge vs. projected sailing line - 65 degrees (see Appendix A)

Effective span width Between Piers for Marine Traffic - 181'

Protection - Three large cells Pier 15

Draw Protection-Pier 14

*(Referred to in remainder of Report as the Fort Madison Bridge)

2.2   River Characteristics - The upper Mississippi River at Fort Madison is very wide and has a number of dikes. There are several stump fields in this area. The downbound approach to the bridge is an S-shaped approach and begins approximately five miles upstream. Although the turns are gradual, during high flows it is reported to be difficult to maintain the tow in proper alignment for passage through the bridge. There is a constriction in the river about 1.5 miles above the bridge with two islands on the right descending bank. Flow can pass around the lower island and reenter the navigation channel between .5 to 1.0 mile (2 1/4 to 4 1/2 tow lengths) above the bridge. The constriction causes an increase in current velocities and the back channel flow causes a crosscurrent at critial points in the approach to the bridge.

In addition, the bridge is built on a landfill extending from the left descending bank that partially blocks the flow of the river and creates a second constriction in the river. This occurs right at the bridge and creates an increase in the current velocities within the navigation opening.

2.3   A hydrographic survey of the Ft. Madison Bridge area was conducted by the U. S. Geological Survey June 25-28, 1984 in support of this study. This survey was used to provide data for the development of the mathematical model of the river flow for the simulator by the U.S. Army Corps of Engineers Waterway Experiment Station. The data included a plot of the stream bottom, profile of the water surface, and discharge under the bridge.

2.4.   Maps describing the current patterns and velocities were developed for

flows of 225,000, 175,000, and 125,000 cubic feet per second (see Appendix A).

These rates represent high to very high flow conditions at the bridge. It

should be noted that flow of this magnitude is not an uncommon occurence. The

current maps reveal that even though velocity of the current increases during

high flow, there is no appreciable change in the direction of the current at

high flow with the existing bottom condition. They also graphically show that

the current flows through the bridge at an angle generally between 17-20 degrees

off the perpendicular to the right (looking downstream) with respect to the

bridge and approximately 6.5 degrees with respect to the line of sail. This

undoubtedly contributes to the difficulty of navigation under the bridge. (See

Figure 2.2)

2.4.1.   Currents - In general the current flows from 1.8 mph (125k cfs) to

approximately 3 mph (225k cfs) with a direction of 249° (as stated above this

is about 6.5 degrees off the line of sail). The modified channel did not

greatly change the magnitude or direction of the current however the reader will

see later that even small changes have a statistically significant impact on

some safety measures. This points out the senitivity of these measures to only

slight changes in currents.

2.5   History - Accident information concerning Ft. Madison Bridge can be

found in CG Report #D-77-76 "Analysis of Bridge Collision Incidents" (Ft.

Madison Summaries) describing 10 casualty cases at the bridge between 1971 and

1974 and Mississippi River Casualty Analysis, for the years 1981-1983. (Draft).

IOWA
(WEST BANK)

RIVER

-N-

PIER
15

PIER
14

PIER
13

MISSISSIPPI

ILLINOIS
(EAST BANK)
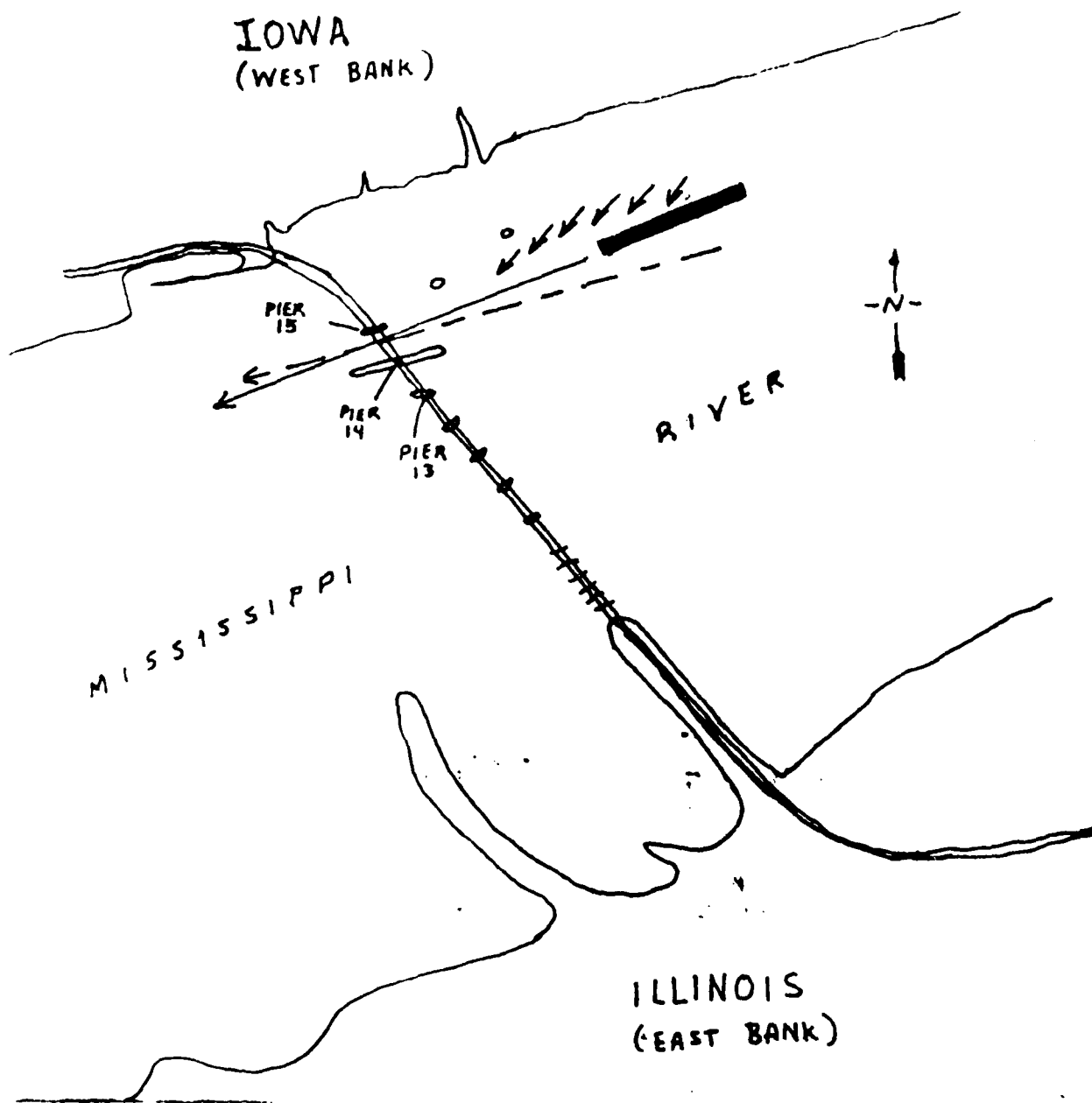
ORIENTATION OF BRIDGE OPENING (PIER 14)- 256°

INTENDED (DESIGN) LINE OF SAIL - 256°

LINE OF SAIL (ESTIMATED) ACTUALLY USED- 251°-253°

DIRECTION OF CURRENTS AT BRIDGE- 249°

TYPICAL FIFTEEN BARGE TOW

Figure 2.2

8

Some conclusions can be drawn from these reports. First, nearly all casualties at Fort Madison occurred going downriver, therefore only the down river traffic was modelled. Also each casualty was stated to have been caused by an error in judgement on the part of the operator in that he misjudged the effects of the current on his tow.

The "Analysis of Bridge Collision Incidents" report also gives empirical data which indicates a correlation between tow horsepower and length during high water conditions. This shows, as suspected, the longer the tow, the more the horsepower required to execute safe passage through the bridge.

3.0 TEST PREPARATION

Preparation for the Ft. Madison Bridge study began by obtaining necessary raw data of bridge and river characteristics at Ft. Madison for generating mathmatical models of the river current and channel visual scene to program into the Coast Guard Maneuvering Simulator. Fast time autopilot runs were then conducted to help determine validity of the model and limit the scope of the test by identifying the approximate sensitivity of critical parameters and appropriate ranges of these parameters for testing. Systems Branch, the Second Coast Guard District and river industry representatives then conferred to help scope and limit the parameters to be studied. Finally, preliminary real time runs with "man in the loop" (river pilots) were done to determine the final parameters for the study.

9

3.1   Simulator - A mathmatical model of the river beginning 22,300 ft.

above the bridge and continuing below the bridge was programmed into the U. S.

Coast Guard Ship Maneuvering Simulator, U. S. Coast Guard Headquarters. G-WP

produced the simulation of the visual characteristics of the river and bridge

from information obtained from the Second Coast Guard District and the U. S.

Geological Survey. River current simulation for flow rates of 125K, 175K and

225K cubic feet per second were provided by the Math Modeling Branch of the

Corps of Engineers Waterways Experiment Station (WES). WES also provided

simulated currents for two proposed modified channels. One was a model of

currents which would be produced by constructing a dike between Dutchman's

Island and the Iowa bank. This theoretically would help align the current more

with the direction of the opening of the bridge (see Fig. 3.1). The other

proposal, which was ultimately selected for use in the simulation runs,

consisted of dredging the area between Dutchman's Island and the Iowa bank.

This deepened area would theoretically reduce the velocity of the current coming

around Dutchman's Island and thus reduce the powerful "left hand set" tows

encounter at the bridge.

The 3900 HP, 15 barge push tow model was produced by Hydronautics,

Inc., Laurel, MD. The 2400 HP and 5400 HP tow characteristics were approximated

using the 3900 HP tow configuation. Though it would have been preferable to use

data from actual 2400 and 5400 HP tows, it was felt that the 3900 HP tow could

approximate the other tows using the HP/RPM cubic relationship and adjusting the

available RPM. If anything, the models would produce results worse than actual

2400 and 5400 HP tows because these approximations do not reflect tows optimally

designed for these horsepowers.

10

Proposed Dike

Dutchman's Islaı

I O W A
LEE COUNTY

ILLINC
HANCOCK COUNT

NIOTA DRAINAGE DISTRICT

Proposed Dredged Area

NIOTA

FORT MADISON

ATCHISON, TOPEKA AND SANTA FE
RAILWAY AND HIGHWAY BRIDGE

Figure 3.1- Ft. Madison Bridge

11

3.2   Fast Time - Several fast time simulated runs using the autopilot

were conducted using each of the 2400, 3900 and 5400 HP tows at each of the

flows of 125K, 175K and 225K CFS. The fast time runs produced real time data

but accomplished a run approximately seven times faster than normal. This

enables collection of real time data in a much shorter time period. The

autopilot was used because there is no visual simulation in the fast time mode

and thus there can be no operator interaction at this speed. The tow's desired

course was plotted into the computer and could be adjusted by moving the

Trackline. The data obtained helped produce a preliminary analysis of

conditions tows face at the bridge and their effects on safety. It also gave an

idea of the proper strategy to use going through the bridge and ultimately

helped to limit the scope of the study.

3.3   Scoping the Project - After the fast time runs were completed a

conference involving representatives of G-WP, the Second Coast Guard District

and the river industry was held to determine the scope and parameters of the

real time pilot simulations. Due to time and money constraints and based on the

fast time results, it was decided to study only the 125K and 225K CFS flows. It

was also decided to limit the study to the 3900 and 5400 HP tows. The 2400 HP

tow was omitted from the study because very few 2400 HP tows pass through Ft.

Madison.

Four well qualified, experienced pilots from the River Industry

Action Committee (RIAC) then visited the simulator facility to help further

limit the scope of the test and assess the value of participation in the study.

Based on their qualitative judgement the proposed Dike was omitted from the

study because of the two options, dredging behind the island seemed to have the

greatest positive impact. They also gave a commitment to provide as many pilots

as possible for the study.

4.0 TEST PROCEDURES

The real time simulation test was conducted by G-WP-2 at the U. S. Coast

Guard Ship Maneuvering Simulator located in room 1204, U. S. Coast Guard

Headquarters, Washington, DC 20593. Eight well qualified river pilots with

experience operating at Ft. Madison participated in the test as well as CPT D.

Dickey, G-WP-2. These pilots were different than the four pilots from RIAC who

conducted the pre-test assessment.

4.1   Each pilot participated in two days of testing and evaluation.

The pilots were required to make 24 randomly selected real time runs (4 runs

each of six different scenarios). The six scenarios were the 3900 and 5400 HP

tows maneuvering in 125K CFS, 225K CFS and the modified (dredged) channel at

225K CFS. The test began at an area approximately one mile above the bridge,

13

near Dutchman's Island, at a speed of 5 mph and a heading of 255°. Because pilots use different strategies approaching the bridge, we did allow pilots to move the tows starting position laterally in the channel so that each felt "in shape" for his particular strategy. (Note - It is interesting that the last five pilots did not change the starting position of their tow indicating some consistency in strategy approaching the bridge).

After an initial briefing covering the purpose and objectives of the project, the area to be studied and simulator operation, each pilot was given adequate time to familiarize himself with the system so that he felt comfortable operating it. The average familiarization time was 1 1/2 hours.

4.2 Simulation Runs: Before each run the pilot was told which specific scenario he would be operating under. During the run he was observed by staff personnel.

Data from each run was collected for analysis. This data included the recording of the following information every 2 seconds: ship's position in X and Y coordinates, ship's speed, RPM used for left and right engine, depth under the bow, rudder angle, drift angle, rate of turn and port and starboard clearance to the bank or bridge pier. After each run the pilot was given a short debriefing described in chapter 7. These debriefings were conducted to obtain pilots comments on the simulator and the run as well as to obtain pilots subjective evaluation.

4.3   Testing Problems - During the first four pilots' runs, it was noted that under certain flows the currents did not seem to depict what the pilots normally experience at Ft. Madison. In particular there was a strong right hand draft experienced approximately 1/2 to 3/4's of the way through the bridge opening that should not have been there. As a result, the first four river pilots "hit" the bridge about 30% of the time. G-WP worked on the current problem along with WES. Initially all the current and bottom contour data was checked and found to be correct. Finally the simulator programs were recompiled to permit a detailed data check of the instant by instant forces/currents acting on the tow. Apparently the recompilation, in and of itself, corrected the problem because the tow immediately began to react correctly. The cause has never been determined. Due to this problem the data obtained from the first four pilots was not used for analysis. Four other pilot's did generate valid data. In order to increase the statistical base CPT D. Dickey, G-WP, also made 48 runs through the bridge. The data analysis of his runs showed very little if any significant difference between his performance vs. the other pilots' performance. Where there is a difference it will be pointed out.

5.0 RESULTS, ANALYSIS AND DISCUSSION

The results of each pilot's run were stored for statistical analysis. The analysis was produced using version 2.1 of the SPSSX statistical package. This analysis was carried out to determine differences between parameters which are related to safety at the bridge. A discussion of the statistical analysis of performance and the effects of horsepower, current, or channel design and their interactions follows.

5.1 Saftey Parameters - The following parameters were considered the most significant or, primary measures of safety of navigation at the bridge. All the data for the statistical analysis was taken from the area which includes the left and right boundaries (pier 15 and pier 14) of the bridge opening.

5.1.1 - Minimum Clearance - This parameter is defined as the distance between the tow and either the left or right hand pier where the tow passes closest to the pier, or, in other words, the minimum distance away from the bridge. If the value becomes negative it means part of the tow has "hit" the bridge. The Minimum Clearance safety parameter is the most important measure of safety, because it is a direct measure of how close the tow came to hitting the bridge.

5.1.2   Maximum Percent Channel Used - This parameter can best be defined by a drawing (see Figure 5.1). It is a measure of the projected width or area used by the tow compared to the width of the opening of the bridge. Its value as a safety measure is important because it helps give an idea of how much of a margin of safety, or available room, is left for the tow. The larger the percent Channel Used, the smaller margin of safety is available. This value is less important than Minimum Clearance because it is possible to hit the bridge without using a large percent of the available channel. This parameter can also be used to help determine optimal design of a navigation span.

5.1.3   Maximum Width Used - Like Percent Channel Used, Width Used can best be described by a diagram (see Figure 5.2). Like Percent Channel used, the Width Used by the tow as it passes through the bridge helps give an idea of how much available channel is left. The larger the width used, the less margin of safety available. However, just as Percent Channel Used, it is not as important as Minimum Clearance.

16

Pier

Pier

b

a
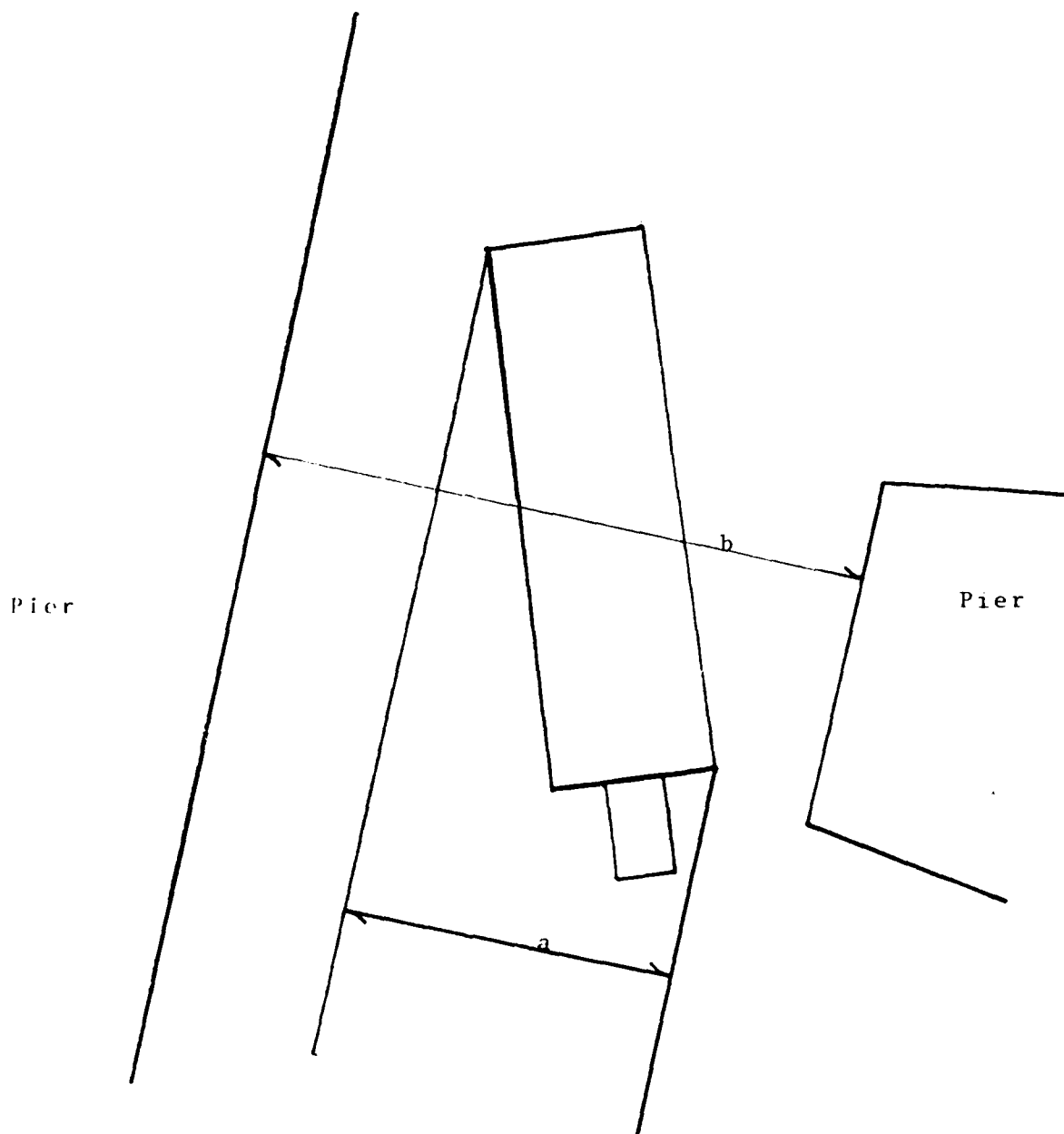
a= Projected Tow width (ft) (maximum value)
b= Width of opening between piers (ft) (maximum value)

Maximum Percent Channel Used (PCU)= a/b

Figure 5.1
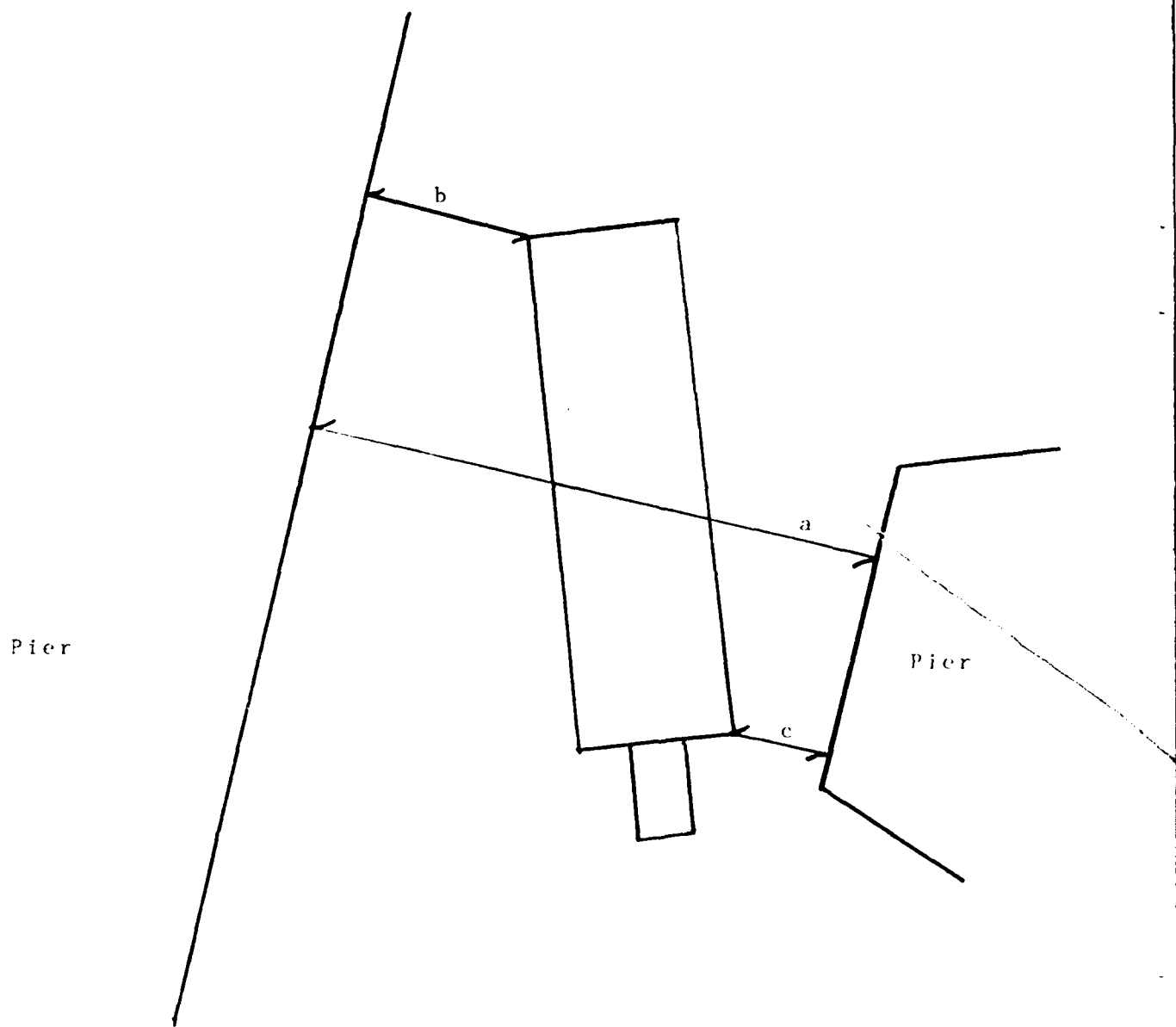
Pier

Pier

a= Width of opening between piers (ft)
b= Distance from left hand pier to closes point on Tow (ft)
c= Distance from right hand pier to closest point on Tow (ft

Width Used= a-(b+c)

Figure 5.2

18

5.1.4   Maximum Rudder Angle: Measuring the amount of rudder used helps give an idea of how hard the pilot is working and maneuvering his tow. It is a safety measure because if a large amount of rudder is used there is less maneuvering capability left for use if the tow gets in trouble.

5.1.5   Minimum Heading - A secondary safety measure, Minimum Heading helps give an idea of pilot strategy and how the tow is approaching the bridge relative to the current. It can also be used in navigation span design, since this parameter gives us the relative orientation of the tow through the bridge.

5.1.6   Other - Horsepower and speed were measured to help better understand pilot strategy and determine their relation to the magnitude of flow. Available horsepower is a safety measure because if a pilot uses all avialable HP he will have none left to help him if he gets in trouble near or at the bridge.

5.2 Scenario - The first statistical procedure was an analysis of variance and multiple range test comparing performance under each of the scenarios.

5.2.1   The primary, but by no means only, measure of safety at the bridge is the Minimum Clearance from the tow to the bridge during a passage. The results of the statistical analyses were plotted to display differences between the various scenarios.

Figures 5.3 - 5.8 show some of the results of the statistical analysis. These graphs have plotted the normal distribution of minimum clearance for each of the scenarios.

19

MINIMUM CLEARANCE OF THE BRIDGE
225 CFS - 5400 HP

LEGEND

Std. Dev. = 86.6
Mean = 13.5
N = 23

cleared bridge

hit bridge

MINIMUM CLEARANCE

Frequency

Figure 5.3

20

MINIMUM CLEARANCE OF THE BRIDGE
225 CFS - 3900 HP

cleared bridge

hit bridge

LEGEND

Std. Dev. = 64.4
Mean = 15.0
N = 24

MINIMUM CLEARANCE

Frequency

Figure 5.4

21
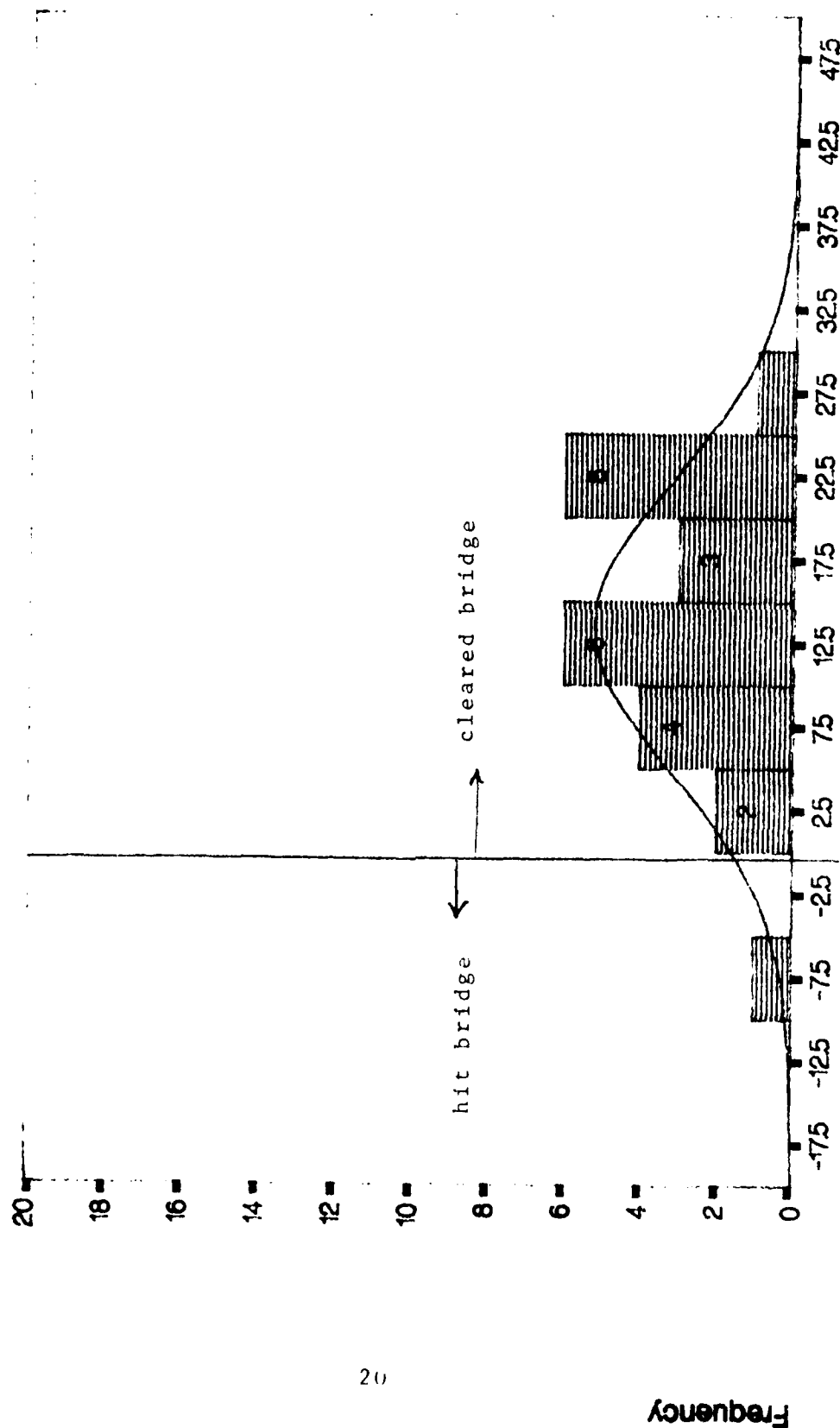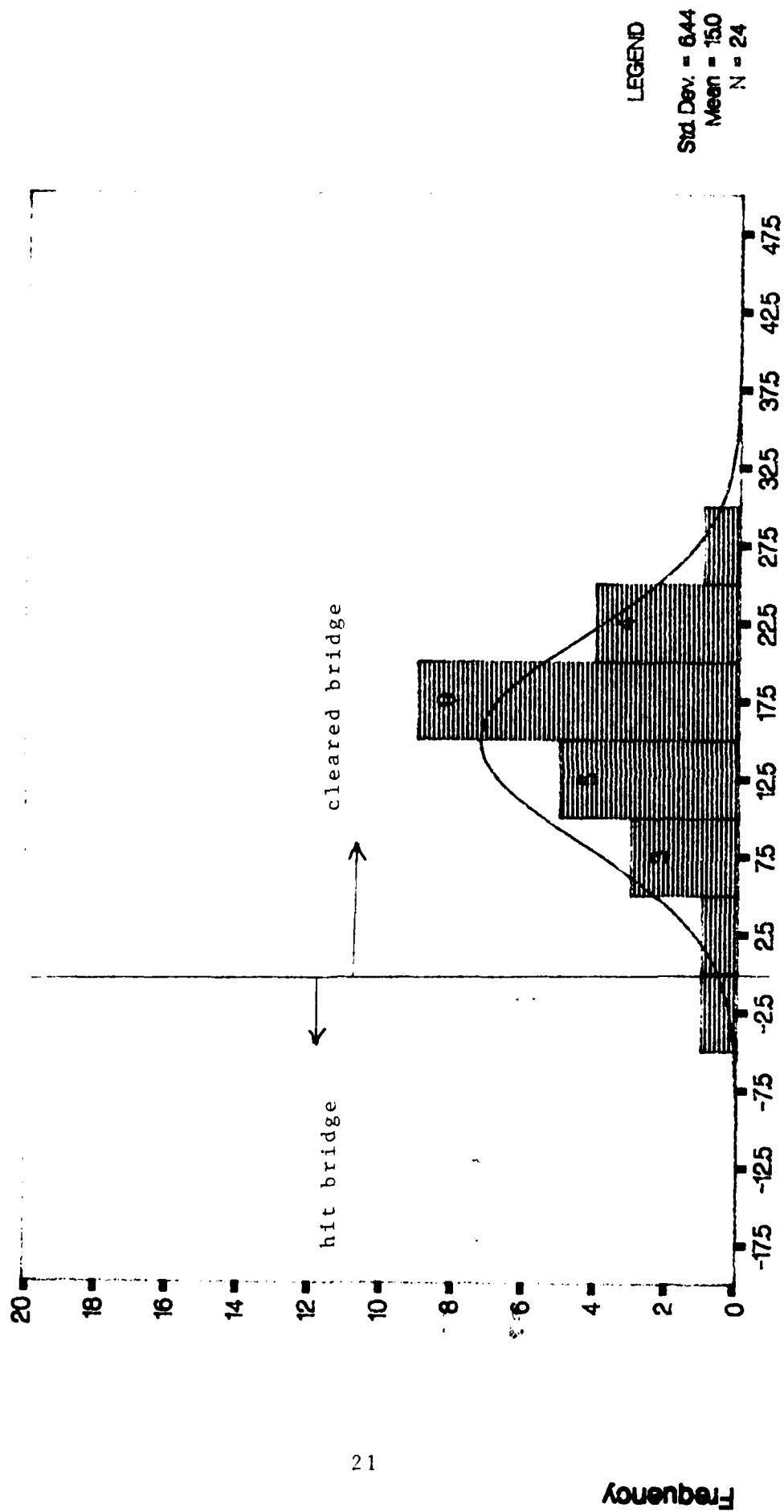
MINIMUM CLEARANCE OF THE BRIDGE
125 CFS - 3900 HP
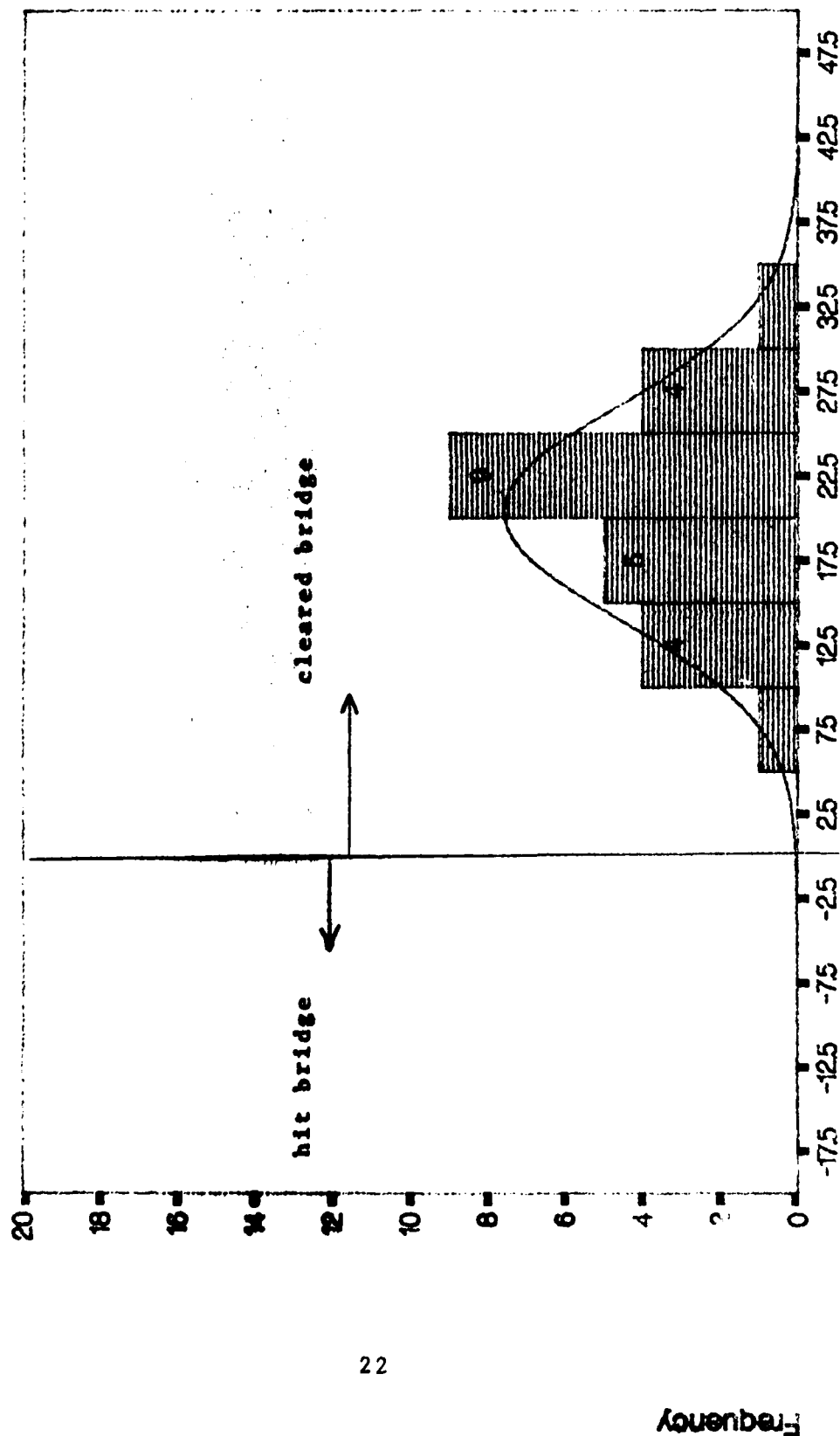
Figure 5.5

MINIMUM CLEARANCE OF THE BRIDGE
225 CFS - 3900 HP MODIFIED

LEGEND

Std. Dev. = 500
Mean = 2053
N = 24

MINIMUM CLEARANCE

Frequency

Figure 5. 6

23
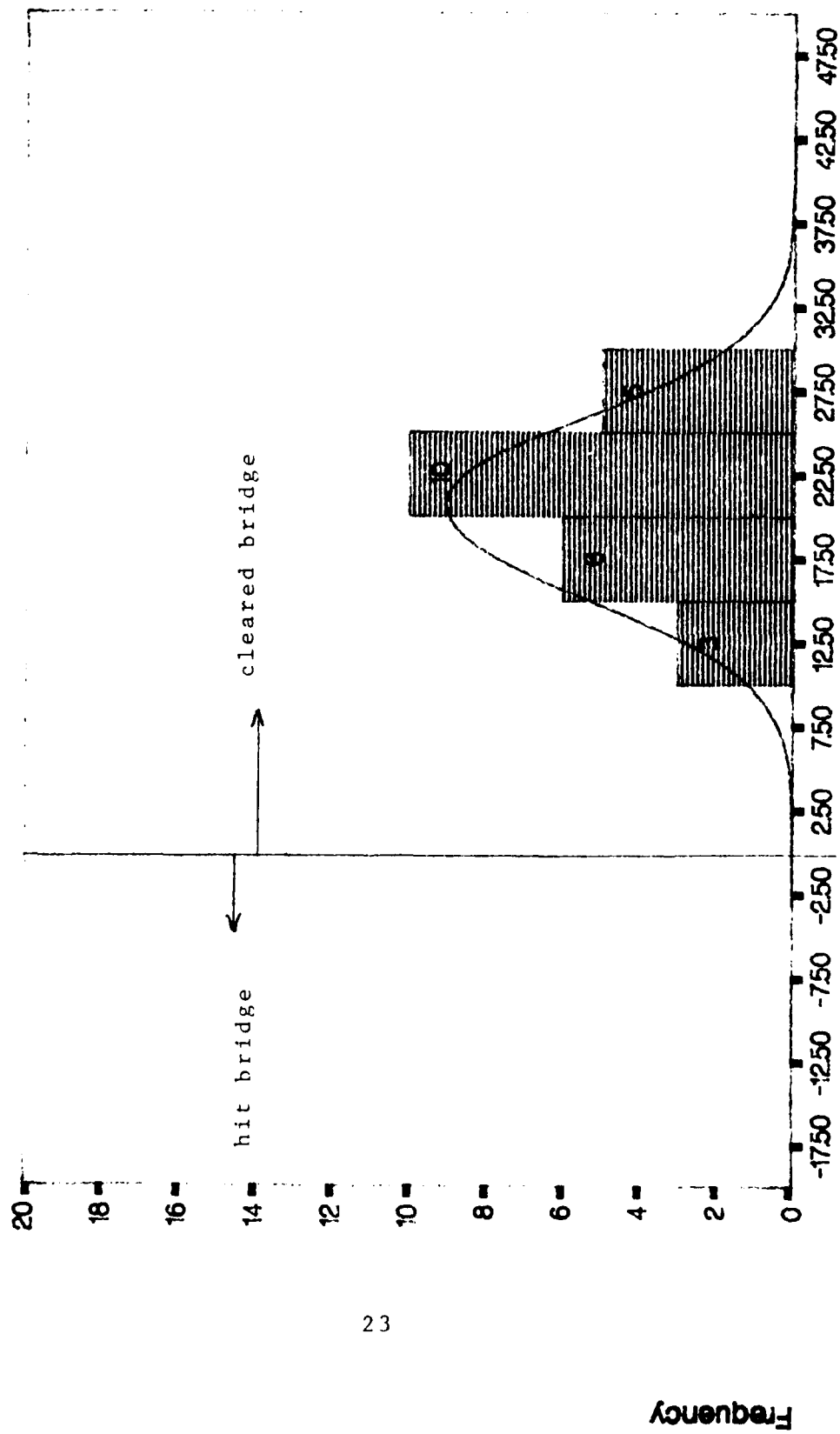
MINIMUM CLEARANCE OF THE BRIDGE
125 CFS - 5400 HP

LEGEND

Std. Dev. = 6.12
Mean = 21.2
N = 24

cleared bridge

hit bridge
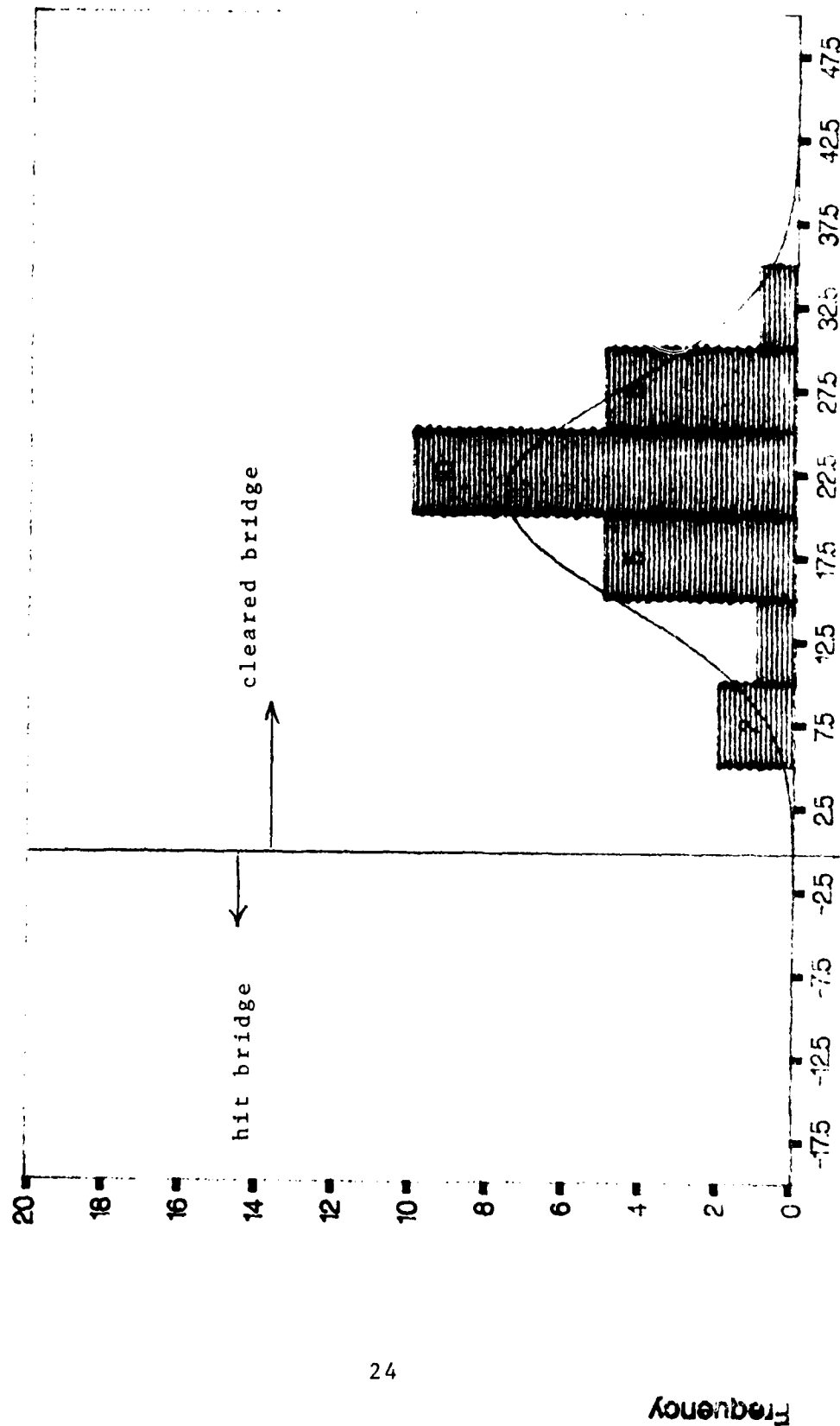
MINIMUM CLEARANCE

Figure 5.7

24

MINIMUM CLEARANCE OF THE BRIDGE
225 CFS - 5400 HP MODIFIED

cleared bridge

hit bridge

LEGEND

Std Dev. = 53.6
Mean = 249
N = 24

MINIMUM CLEARANCE

Frequency

25
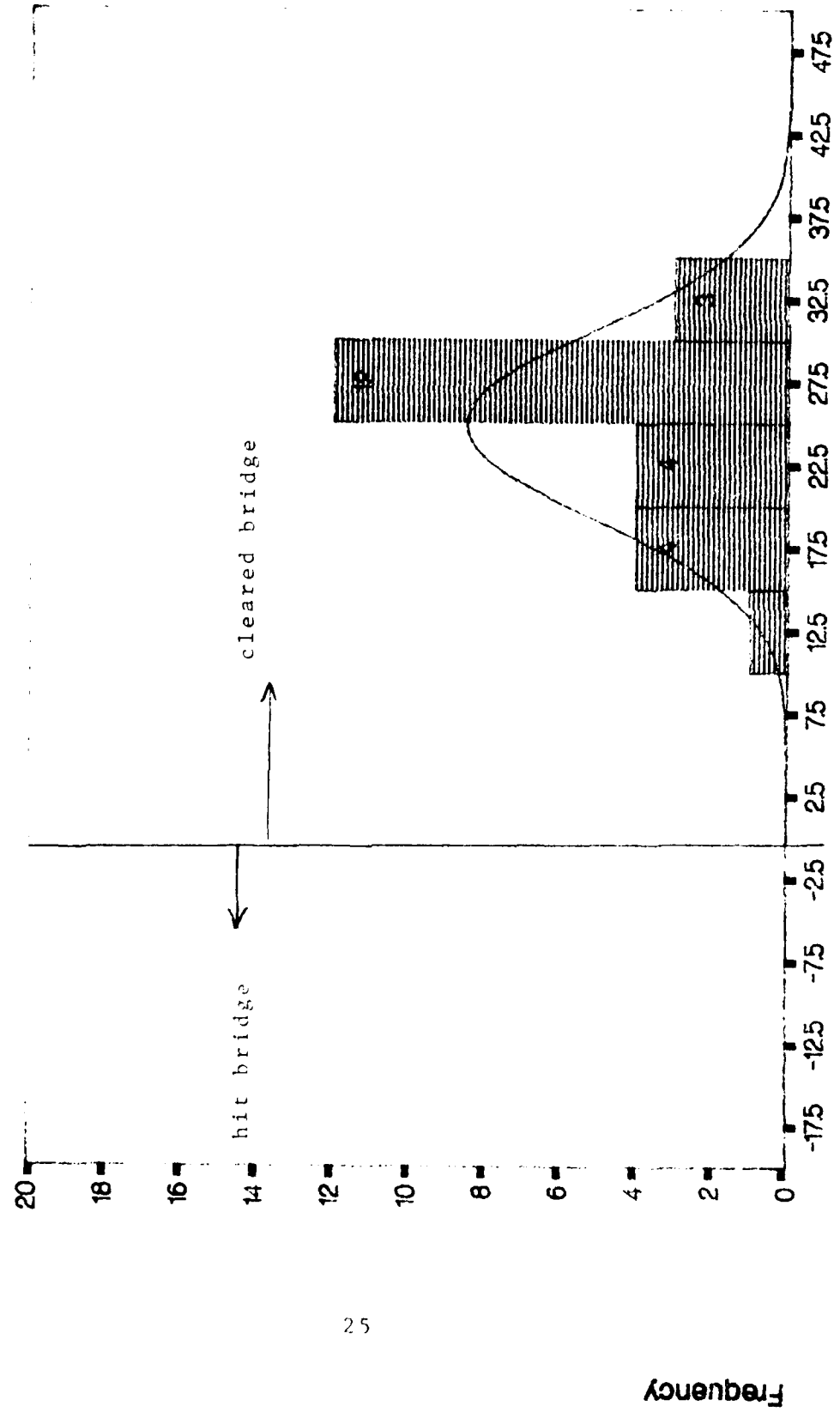
Figure 5.8

Figure 5.3 - 5.8 indicates poorest performance using both the 5400 and 3900 HP tow at the highest flow rate (225k cfs). The best performance is obtained by a 5400 HP tow under the modified channel conditions.

As you can see from these figures, the mean Minimum Clearance for the worst case scenario, a 5400 HP tow operating in 225k cfs, is 13.5 feet between tow and pier, and the mean Minimum Clearance for the best case, a 5400 HP tow operating in the modified channel, is 24.9 feet, an improvement in this primary safety measure of over 10 ft.

Table 5.9 indicates there is a statistically significant difference in Minimum Clearance between the 5400 HP tow operating in 225k cfs and all other scenarios but one, the 3900 HP tow at 225k cfs. Thus, the 5400 HP, 225k cfs scenario does produce significantly lower clearances than every other scenario but one, and the 5400 HP tow operating in the modified channel produces significantly better results than both the 3900 HP and 5400 HP tows operating in 225k cfs.

Variable	MINIMUM CLEARANCE (FT)
By Variable	SCENARIO NUMBER

MULTIPLE RANGE TEST

(*) DENOTES PAIRS OF GROUPS SIGNIFICANTLY DIFFERENT AT THE 0.050 LEVEL (95%
confidence)

```
          H H H H H H

          5 3 3 3 5 5

          4 9 9 9 4 4

          C C C C C C

          2 2 1 M 1 M

          2 2 2 0 2 0

          5 5 5 D 5 D
```

Mean	Scenario		
13.5157	H54C225		
14.9646	H39C225		
20.3262	H39C125	*	
20.5325	H39CMOD	*	
21.2054	H54C125	*	
24.9115	H54CMOD	*	*

H   Horsepower

54 - 5400

39 - 3900

C - Current

125 - 125,000 cfs

225 - 225,000 cfs

MOD - Modified Channel with a flow of 225,000 cfs

Table-5.9

The question then is, what are the chances of hitting the bridge. In this study the bridge was "hit" once (-9.93 Ft into the bridge) and "brushed" once (-.03 feet into the bridge). However inspection of Figures 5.3 thru 5.8 shows that however slight and under the conditions tested, for a large number of runs through the bridge there is a chance of hitting the bridge (i.e. a negative clearance) for 3 out of the six scenarios. These occur when the 3900 and 5400 HP tows are operating in 225,000 cfs and for the 3900 HP tow operating in 125,000 cfs.

5.2.2   Maximum Percent of Channel Used and Maximum Width Used - Two other primary measures of safety comparable to Minimum Clearance that were analyzed are Maximum Percent of Channel Used and Maximum Width Used, both comparable but slightly different from each other. (See Figures 5.1 and 5.2 for description)

Data in figures 5.10 thru 5.15 seem to contradict the trend noted in the analysis of Minimum Clearance. As seen in Table 5.16 the two worst cases occured under the modified channel conditions, with mean value of 86.5% and 84.4% of the channel used by the 3900 HP and 5400 HP Tows respectively. The lowest mean value for Maximum Percent Channel used is 80.55% for a 5400 HP tow operating in 225k cfs operating in the regular channel. Though smaller than the figures obtained for Modified Channel conditions, it is important to note that 80.5% of channel used is not a small percentage. This will be discussed later.

28

MAXIMUM PERCENT OF OPENING USED
125K CFS - 5400 HP
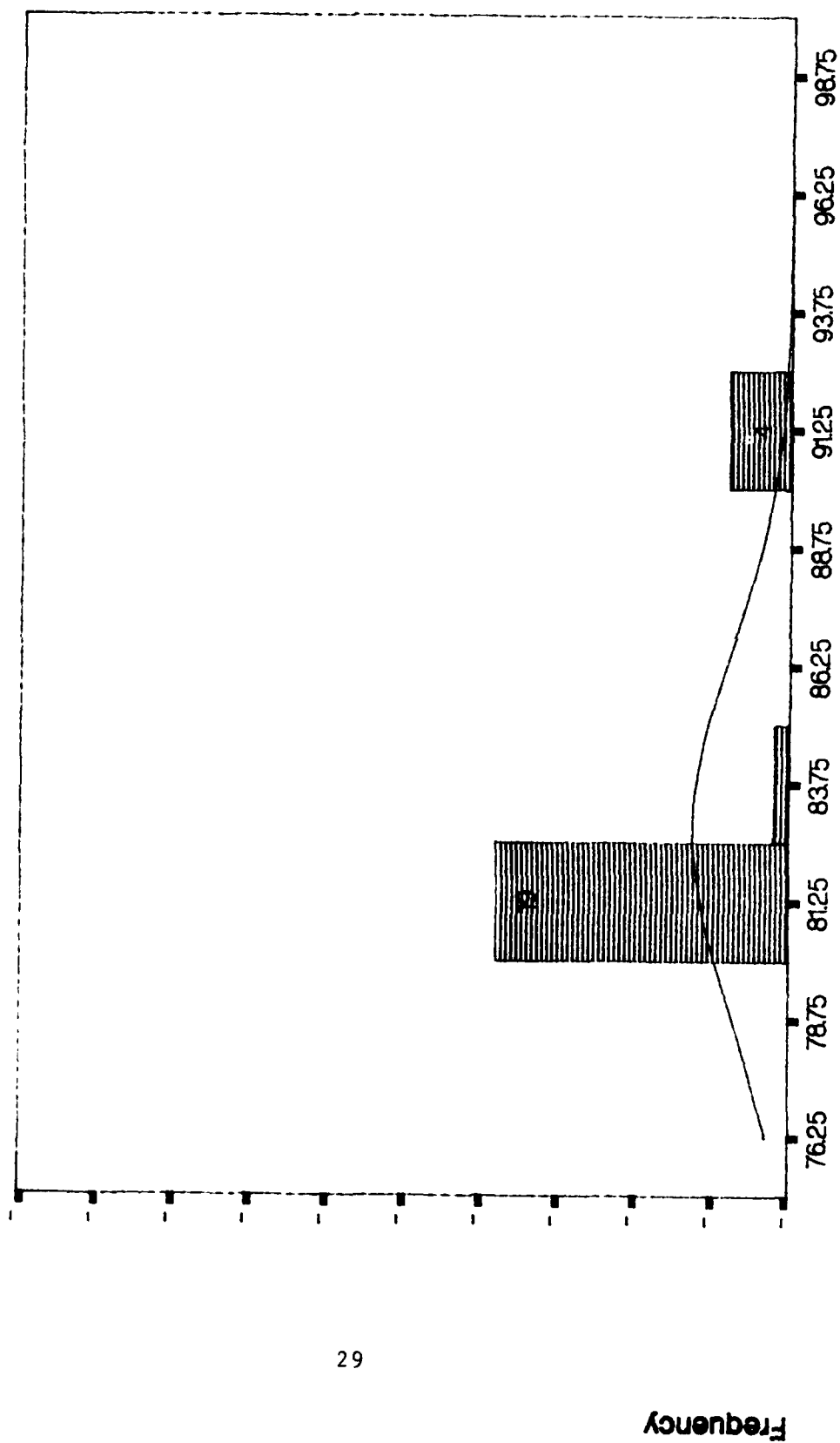
LEGEND

Std. Dev. = 3.77
Mean = 82.75
N = 24

MAX % WIDTH USED

Frequency

Figure 5.10

29

MAXIMUM PERCENT OF OPENING USED
225K CFS - 5400 HP

LEGEND

Std Dev. = .87
Mean = 80.55
N = 23

76.25 78.75 81.25 83.75 86.25 88.75 91.25 93.75 96.25 98.75

MAX % WIDTH USED

Frequency

Figure 5.11

30

MAXIMUM PERCENT OF OPENING USED
225K CFS - 5400 HP MODIFIED

LEGEND

Std. Dev. = 4.27
Mean = 84.38
N = 24

Frequency

MAX % WIDTH USED

76.25 78.75 81.25 83.75 86.25 88.75 91.25 93.75 96.25 98.75

31
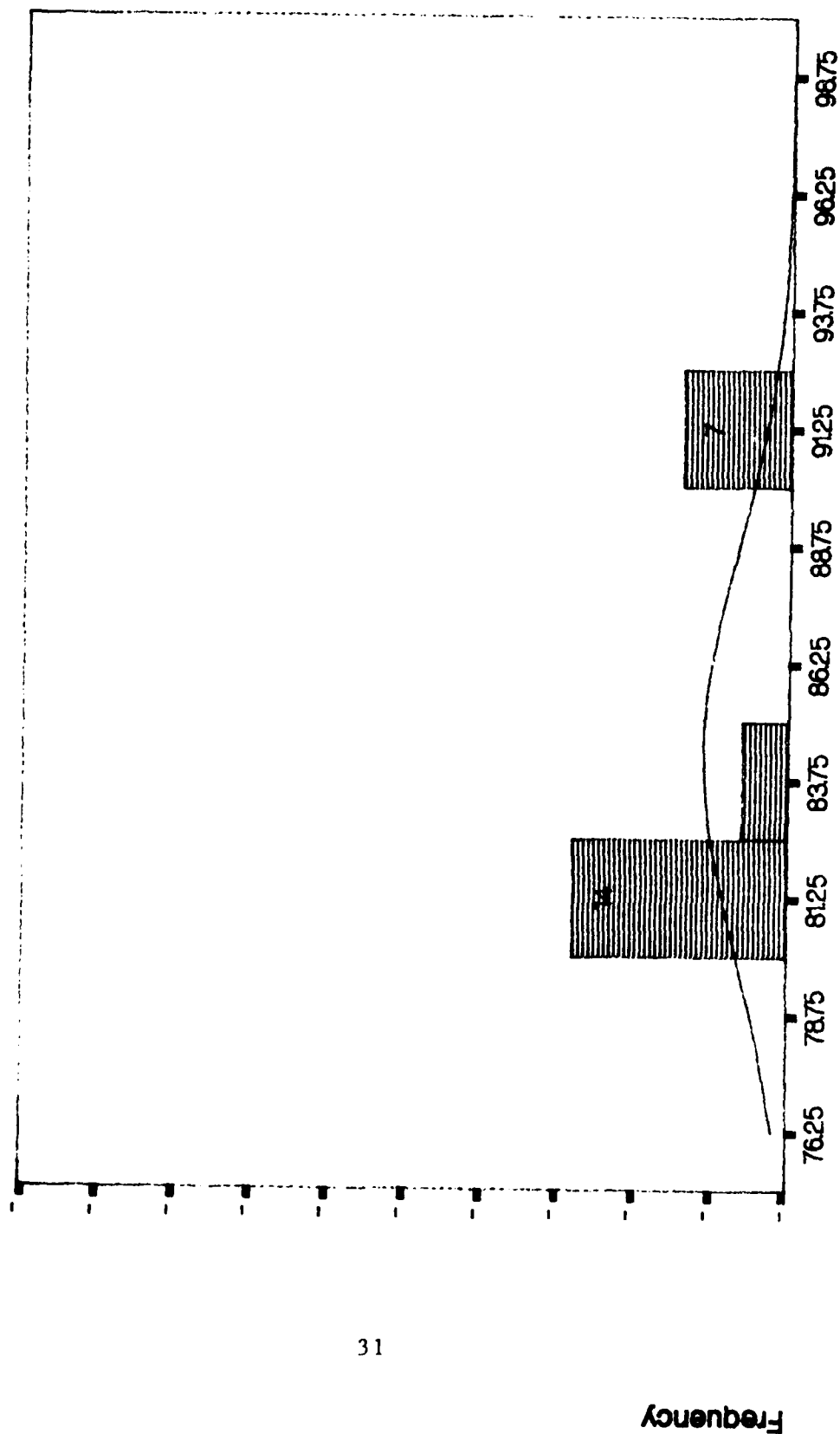
Figure 5.12

MAXIMUM PERCENT OF OPENING USED
125K CFS - 3900 HP
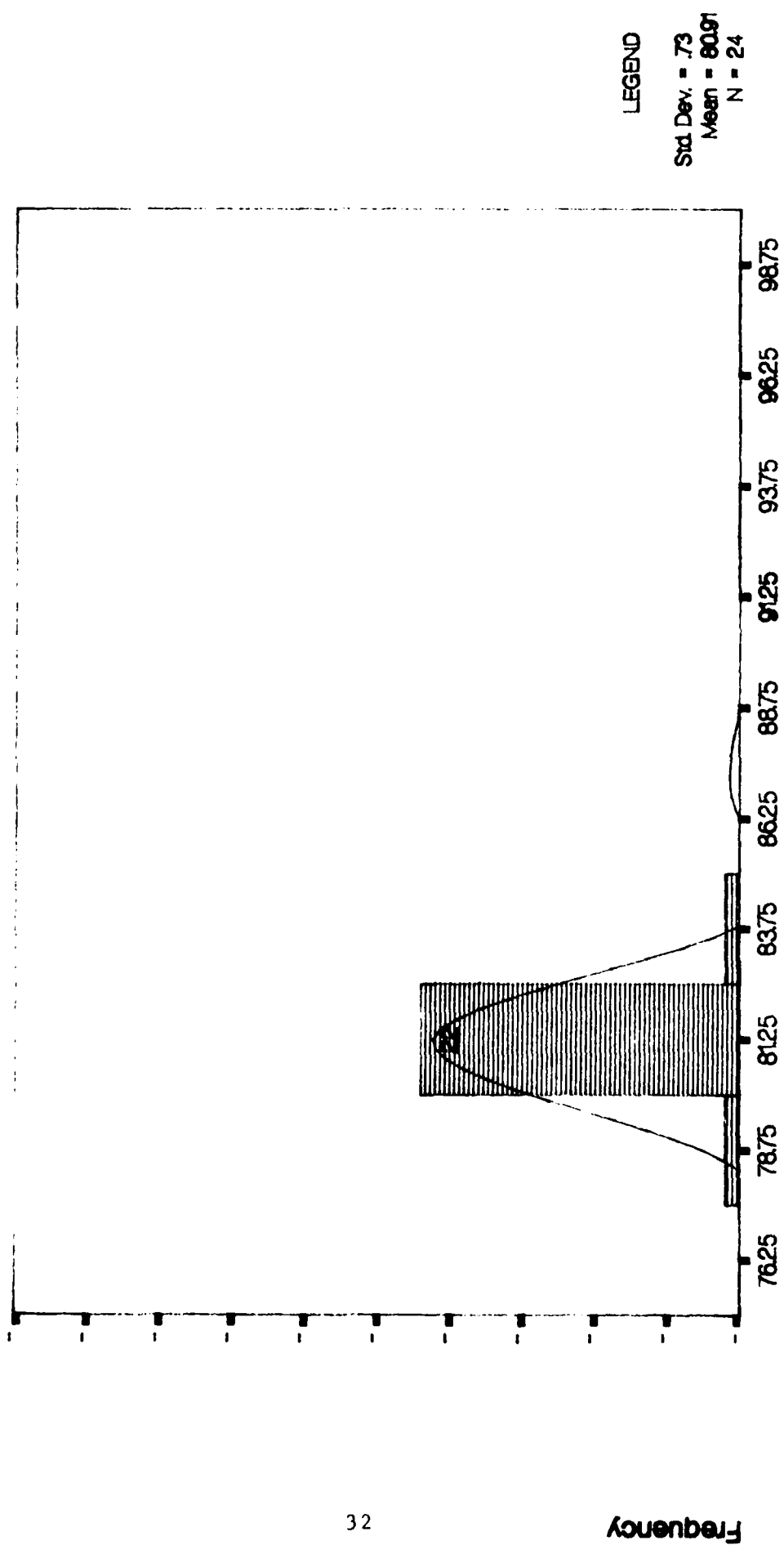
LEGEND

Std Dev. = .73
Mean = 80.91
N = 24

MAX % WIDTH USED

Frequency

Figure 5.13

32

MAXIMUM PERCENT OF OPENING USED
225 CFS - 3900 HP

LEGEND

Std Dev. = 2.30
Mean = 80.89
N = 24

Frequency

MAX % WIDTH USED

7625 7875 8125 8375 8625 8875 9125 9375 9625 9875

Figure 5.14

33

MAXIMUM PERCENT OF OPENING USED
225 CFS - 3900 HP MODIFIED

LEGEND

Std. Dev. = 4.60
Mean = 86.49
N = 24
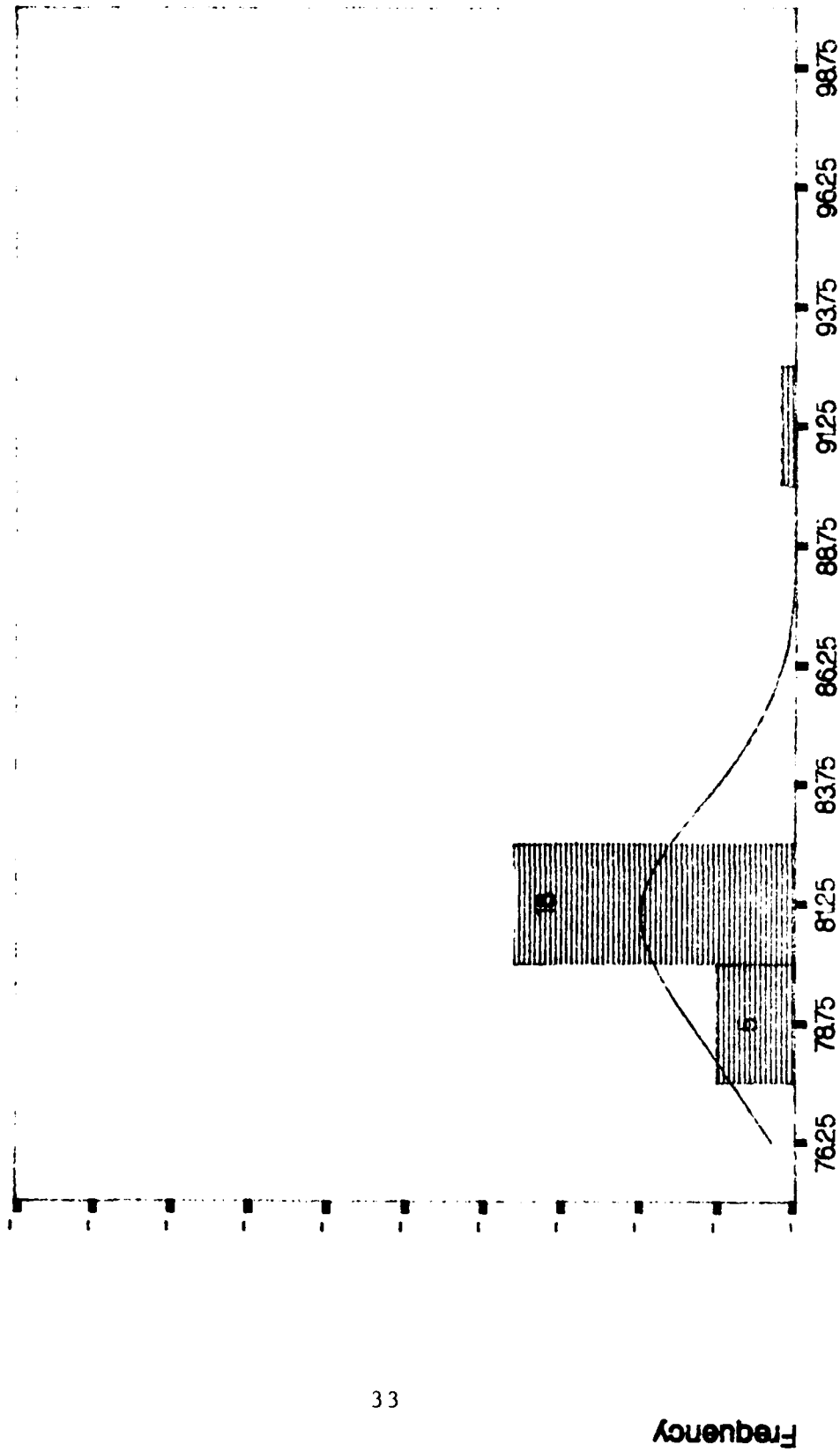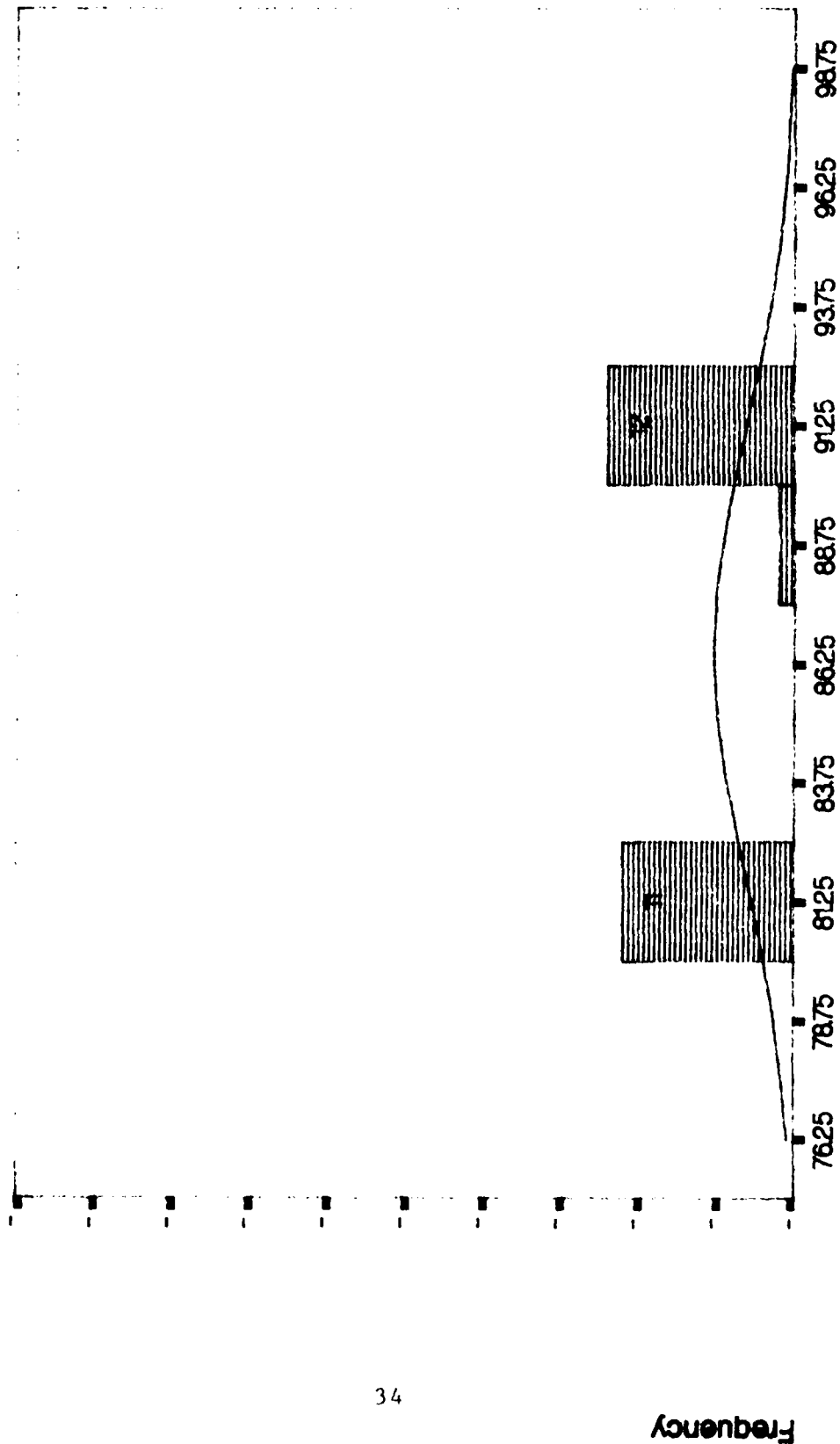
MAX % WIDTH USED

Figure 5.15

34

Frequency

Variable	MAX % WIDTH USED
by Variable	SCENARIO NUMBER

MULTIPLE RANGE TEST

(*) DENOTES PAIRS OF GROUPS SIGNIFICANTLY DIFFERENT AT THE 0.050 LEVEL

(95% confidence)

An * indicates that performance was statistically significantly different between a particular scenario and each of the scenarios where an * appears in a column.

```
                              H H H H H H

                              5 3 3 5 5 3

                              4 9 9 4 4 9

                              C C C C C C

                              2 2 1 1 M M

                              2 2 2 2 0 0

                              5 5 5 5 D D
```

Mean Percent C.U.	Scenario					
80.5500	H54C225					
80.8942	H39C225					
80.9071	H39C125					
82.7529	H54C125					
84.3808	H54CMOD	*	*	*		
86.4938	H39CMOD	*	*	*	*	

Table-5.16

35

One possible, and probable explanation for the apparent contradiction in trends

noted between Minimum Clearance and Percent Channel used can be gleaned from the

graphs. You can see that for most of the scenarios except the modified, most of the

runs are gathered in a tight group with little deviation from the mean. However for

both of the modified scenarios (5400 & 3900 HP) there is a wide deviation between

pilot performance. This is most likely due to the pilots unfamiliariaty with these

currents and their inability to pick out a consistant path or strategy. One other

possible explanation is the increased drift angle under the modified conditions.

Table 5.16 shows a significant difference in the performance of the tow under the

modified channel conditions versus all other scenarios. This statistical difference

however is not that great in absolute terms and should not be considered a

contradiction to the MINCL values, or as having more significance than MINCL.

Width used, a secondary safety measure, was analyzed against channel design, HP,

and current. As in MAXPCU design affects the width used more than any other factor.

The modified channel had the largest width used figure, over 143 feet. The

explanation for the apparent contradiction is the same as that for MAXPCU. Minimum

clearance is the point where the tow passes closest to the bridge and is therefore the

most important safety parameter. Under regular channel conditions the tow approached

the bridge much closer but used less channel.

5.2.3 Maximum Rudder Angle and Minimum Heading – Two secondary safety

measures analyzed were Minimum Heading and Maximum Rudder Angle. The minimum heading

helps determine differences in pilot strategy as he approaches the bridge, and the

Maximum Rudder Angle needed gives an indication of how much control, or available

rudder, the pilot has to make his passage. Generally the more rudder used, the less

remaining control the pilot has over the tow.

36

There was a difference in the Minimum Heading for each scerario indicating the pilots adjusted their strategy as the current increased.

The average Minimum Heading was lower for the two 225k cfs scenarios, 251.6° and 251.9°. (see Table 5.17) These figures are close to the current angle (249°) and verify the generally accepted strategy of trying to run with the current under high flow conditions to avoid being pushed into the swing span. What is interesting here is that the modified channel scenario produces minimum heading angle closer to the angle of the opening of the bridge (255°). The figures indicate that the strategy used by pilots for the modified channel scenario, even in the high flow condition, is closer to the approach they would use under low flow and generally safer conditions than under similar conditions in the existing channel configuration.

The figures for Maximum Rudder Angle used indicate that the pilots use more rudder under the modified channel scenario. (see Table 5.18) The general trend was to use less rudder with the 3900 HP tows and more with the 5400 HP tow. This is another indication of the pilots' strategy which is to get lined up or "in shape" for the approach and then use very little rudder in order to have available rudder in case it is needed. It is probable that the larger horsepower boat used a little more rudder because the pilots felt they did not have to save as much. It is difficult to ascertain why the pilots' used more rudder under the modified channel scenario. One possibility is, as mentioned previously, is that they simply were not familiar with the modified channel.

37

Variable   HEADING (DEGREES)

By   Variable   SCENARIO NUMBER

MULTIPLE RANGE TEST

(*) DENOTES PAIRS OF GROUPS SIGNIFICANTLY DIFFERENT AT THE 0.050 LEVEL

   (95% confidence)


```
                                    H H H H H H

                                    5 5 3 5 5 3

                                    4 9 9 4 4 9

                                    C C C C C C

                                    2 2 1 1 M M

                                    2 2 2 2 0 0

                                    5 5 5 5 D D
```


Mean	Scenario					
251.8001	H54C225					
251.9610	H39C225					
252.4870	H39C125	*	*			
252.7025	H54C125	*	*			
253.4595	H54CMOD	*	*	*	*	
253.5773	H54CMOD	*	*	*	*	

Table-5.17

38

Variable   MAX RUDDER ANGLE

By   Variable   SCENARIO NUMBER

MULTIPLE RANGE TEST

(*) DENOTES SCENARIOS SIGNIFICANTLY DIFFERENT AT THE 0.050 LEVEL

   (95% confidence)


```
H H H H H H

3 3 5 5 5 3

9 9 4 4 4 9

C C C C C C

2 1 1 2 M M

2 2 2 2 0 0

5 5 5 5 D D
```

Mean	Scenario	
5.9001	H39C225	
8.3583	H39C225	
10.8875	H39C125	
11.0043	H54C125	
14.6125	H54CMOD	
16.4917	H54CMOD	*

TABLE-5.18

39

The modified channel conditions used the greater percent of the channel going through the bridge and required greater rudder angle, indicating possibly less control. One other interesting result is the difference in heading. There is a significant difference in heading as the currents change. The lowest heading at 251.80 degrees is at the high flow and out of line with the bridge opening by approximately 5 degrees. Low flow brings the heading more in line with the bridge and the modified flow appears to bring the tow even more in line with the angle of the bridge opening at a mean of 253.6°.

5.2.4   In summary there is a significant improvement in the primary safety measure, Minimum Clearance, when the channel was modified. However, in the Secondary Safety measures of Percent Channel used and Rudder Angle the pilots performance was worse under the modified channel scenario. It is believed that this is due to the pilots' unfamiliarity with the modified channel conditions and therefore is less of a significant result as the primary safety measure Minimum Clearance.

5.3   It appears, based on the initial statistical analysis that current is more of a factor than horsepower and that the modified channel design may provide a safer passage through the bridge. However, other factors such as pilot performance, different performances for each replication and finally an analysis of horsepower, current and design separately, must be performed prior to making any conclusions.

5.3.1   Pilot Performance - The same analysis of variance and multiple range tests were conducted using the pilot as the dependent variable.

These tests were conducted to determine if there were any significant differences in pilot performance which may affect the validity of the results. They were also run to determine if CPT Dickey's performance was significantly different than the other pilots. CPT Dickey's performance (PILN 7) was ironically, somewhat better than the other pilots.

The measures examined against pilot performance were the same as those for scenario, minimum clearance, maximum width used, maximum percent of the channel used minimum heading and maximum rudder angle. If one or more pilots were consistently an outlayer in these categories it would be one indication that the data could be skewed and therefore not be valid. On the other hand this might imply that we had not selected a representative sample of the total population of pilots. Differences in pilot performance are to be expected. They have different strategies and capabilities. These differences, it should be emphasized, are not a major concern unless they are shown to be of such a magnitude and consistency that they prove to be statistically significant, thus raising the issues mentioned above.

The statistical analyses indicate that there are <u>no significant differences in pilot performance</u> across the board, for the major and secondary measures of safety.

5.3.2   Replication - Replications were scrutinized using the same statistical tests to see if there were significant differences in performance based on scenario replication. <u>Replication played no significant role</u>. This means that during the period that data was being collected for analysis (post familiarizations) that their performance was not changing as a result of continued learning.

41

Though CPT Dickey achieved the "best" minumum clearance data, he was only significantly different from pilots 9 and 10. When the runs were statistically analyzed without CPT Dickey's data there were no major differences in the results, with the exception of the effect of scenario and replication on maximum rudder angle used. CPT Dickey used more rudder than the other pilots.

It is also possible that pilot performance could be a major contributing factor to lack of safety at the bridge. The results of the statistical analysis indicate that the pilots, though different at times in strategy such as heading, speed, RPM, etc., do not differ significantly in their ability to clear the bridge. Each pilot was able to pass through the bridge opening with average minimum clearances of about 19 feet.

5.4 - Horsepower, Current and Channel Design vs Minimum Clearance - The final analysis of variance test was conducted to determine which of the factors that make up each scenario, horsepower, current, or channel design, had the greatest effect on each performance measure. Each performance measure (e.g., minimum clearance) was the dependent variable while horsepower, and current were used as continuous explanatory variables, and channel design was used as a category variable. This test produced some very interesting results.

5.4.1 - Horsepower - The statistical analysis run told us that current and channel design both have a significant affect on performance, i.e., there is at least a 95% chance that current and channel design caused a difference in the performance measure minimum clearance. Surprisingly, under the conditions tested, horsepower did not have a major affect on performance at the bridge. (see Tables 5.19 and 5.20)

42

<u>Significant Effect</u>

MINIMUM CLEARANCE

BY   CURRENT

HORSEPOWER

DESIGN

Source of Variation	Significant Effect on Mincl
Effects	
CURNT	Yes
HP	No
DESN	Yes

Table 5.19

Variable MINCL   MINIMUM CLEARANCE (FT)

ANALYSIS OF VARIANCE

GROUP	COUNT	MEAN	STANDARD DEVIATION	STANDARD ERROR	MINIMUM	MAXIMUM	95 PCT CONF INTERVAL FOR MEAN
HP 5400	71	19.9670	8.3668	.9930	-9.9300	32.7300	17.9867 TO 21.9474
HP 3900	72	18.6078	6.4634	.7617	-0.0300	32.0100	17.089C TO 20.1266
TOTAL	143	19.2827	7.4740	.6250	-9.9300	32.7300	18.0471 TO 20.518-

Table 5.20

44

This seems to contradict previous assumptions that greater horsepower would provide better performance. The explanation most likely lies in pilot ability and familiarity with the conditions at the bridge. Some pilots commented that HP is really a critical factor when you are trying to get your tow out of trouble, e.g. if a tow is out of shape going into the bridge the extra horspower would help get the tow back in shape. During our test runs all of the pilots were good pilots with experience at Fort Madison. Therefore, not surprisingly, they all approached the bridge in good shape and required little adjustment in their approach and therefore did not need the extra HP to get themselves out of trouble. A significant improvement can be seen in HP vs Minimum Clearance when you look at only the modified channel configuration, a situation the pilots were unfamiliar with. The following figures give a better understanding. The first figure 5.4.1 shows a comparison of minimum clearance vs HP for all 225,000 cfs conditions (This includes the modified design). Here you see an improvement in the minimum clearance of 1 ft. for each 1000 HP added. When you separate the regular and modified conditions out there is a striking contrast. Under regular conditions (figure 5.4.2) there is actually a negative value, i.e., the minimum clearance gets worse as HP increases. Under the modified conditions (figure 5.4.3) there is a 3 ft. increase in minimum clearance for every 1000 HP added.

MINIMUM CLEARANCE BY HORSEPOWER
225K CFS FLOW   REGULAR and MODIFIED CHANNEL

LEGEND

MINIMUM CLEARANCE

RSq = .010
Int = 13.625
Lin = .001
SE Reg = 7.974

*   predidted mean clearance
**   95% confidence boundary for mean clearance
*** 95% confidence boundary for a given observation
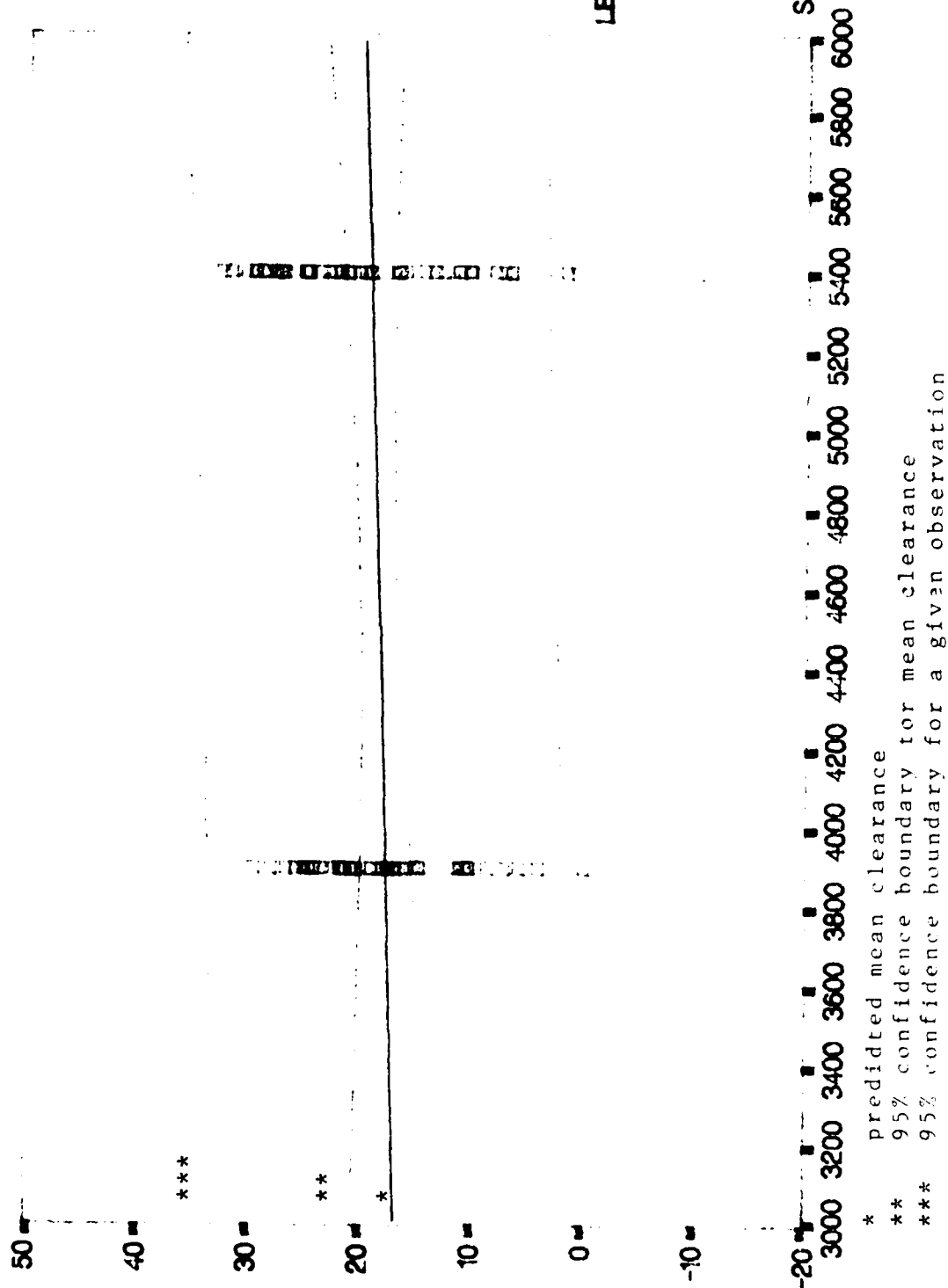
Figure 5.4.1

HORSEPOWER

MINIMUM CLEARANCE

46

MINIMUM CLEARANCE BY HORSEPOWER
225K CFS FLOW

REGULAR CHANNEL
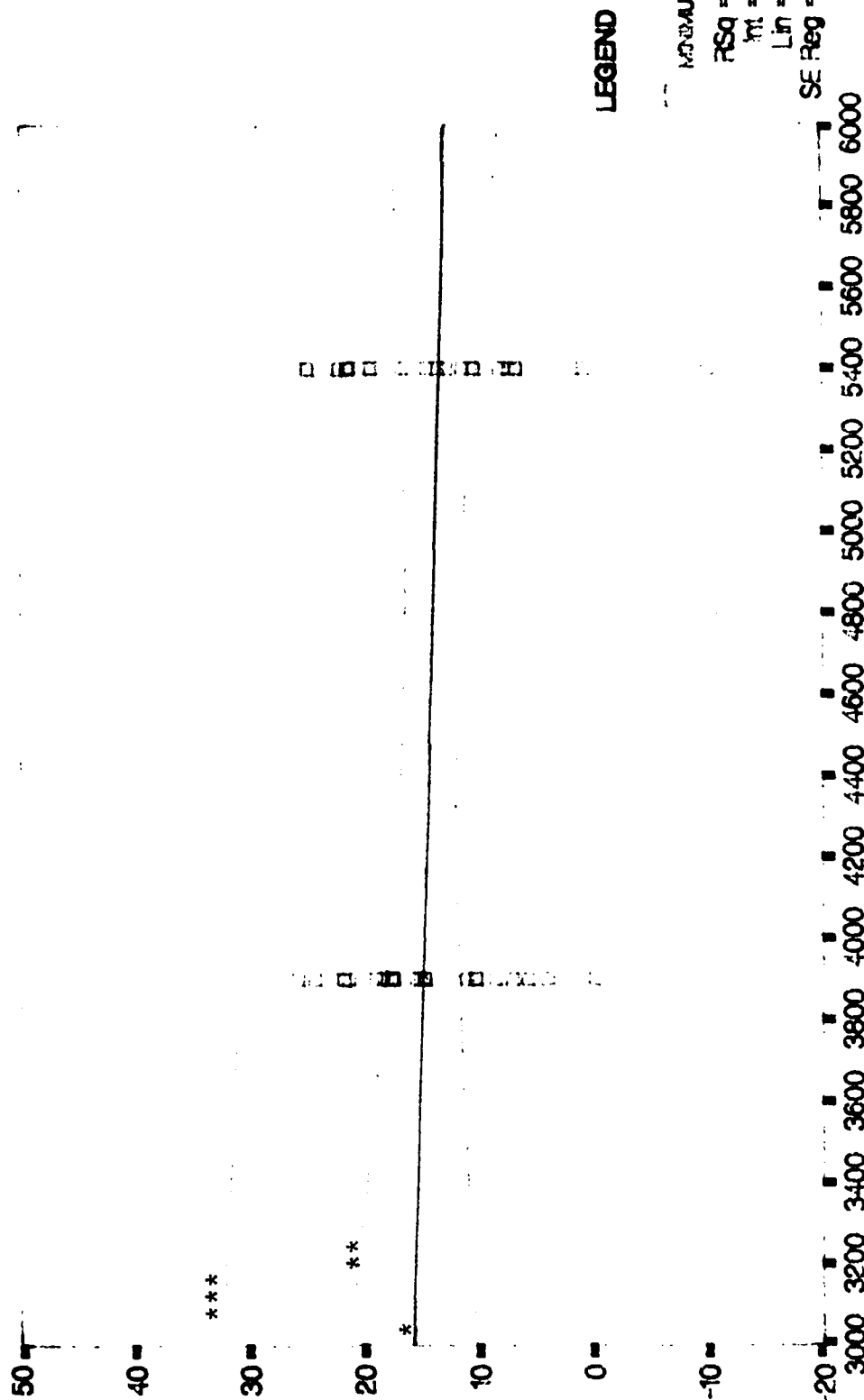
MINIMUM CLEARANCE

HORSEPOWER

3000 3200 3400 3600 3800 4000 4200 4400 4600 4800 5000 5200 5400 5600 5800 6000

50
40
30
20
10
0
-10
-20

* predicted mean clearance
** 95% confidence boundary for mean clearance
*** 95% confidence boundary for a given observation

Figure 5.4.2
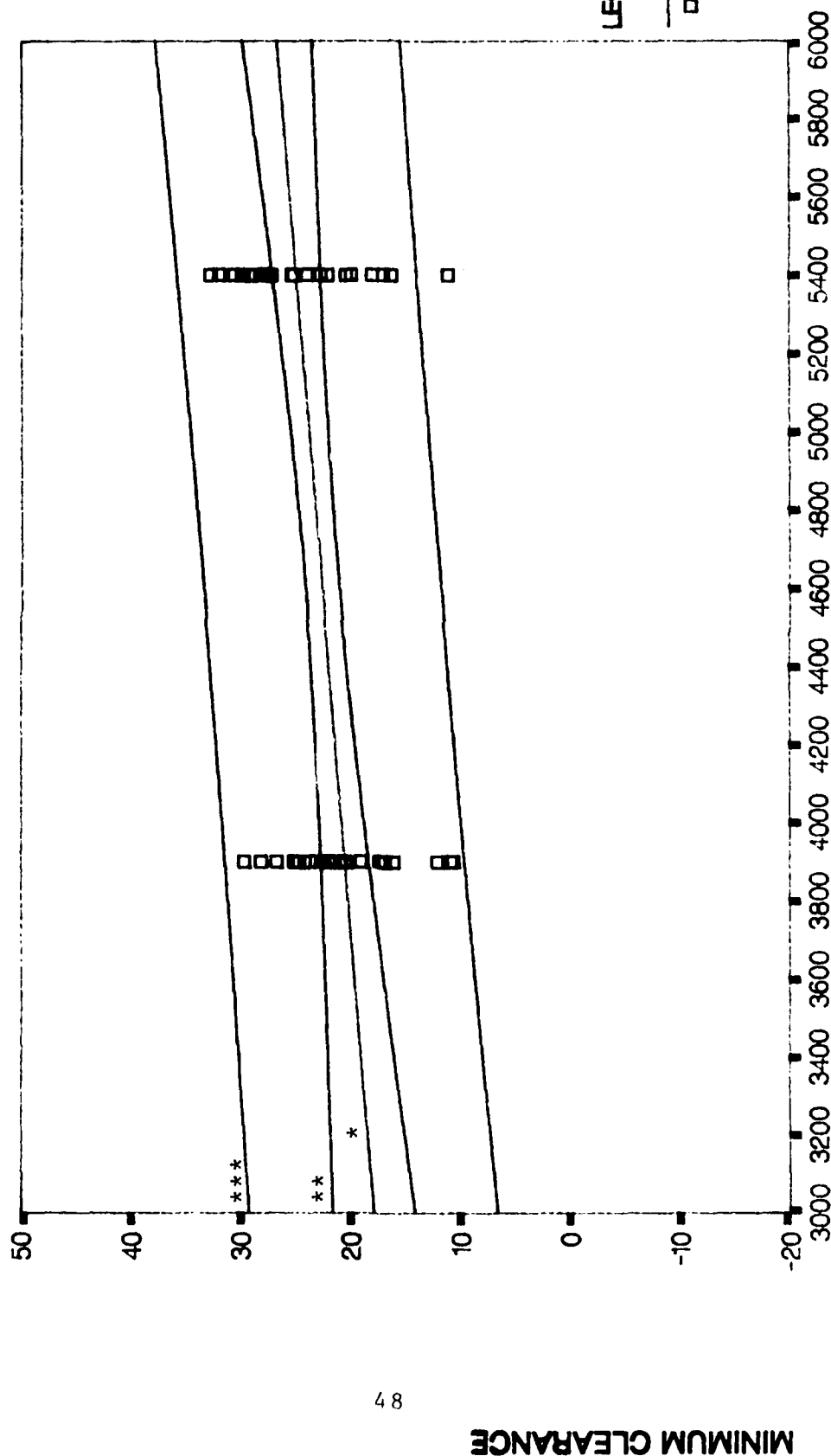
47

MINIMUM CLEARANCE BY HORSEPOWER
MODIFIED CHANNEL   225,000 CFS FLOW

* predicted mean clearance
** 95% confidence boundary for mean clearance
*** 95% confidence boundary for a given observation

HORSEPOWER

MINIMUM CLEARANCE

LEGEND

□ MINIMUM CLEARANCE

RSq = .151
Int = 9148
Lin = .003

48

5.4.2   *Current* - *The effect of current and channel design on the value of* minimum clearance was examined.   Table 5.21 shows us that, as expected, there is a greater clearance distance obtained under a low flow, 125K CFS, than under a high flow.   It should be noted that the high flow contains both modified and regular channel design data.   As in Horsepower, when you look at only the regular channel configuration we see an interesting trend.   When considering only regular channel flow, Table 5.21 indicates a mean MINCL value of 20.76 ft for 125,000 cfs flow, 6.5 feet better than the 14.25 ft mean MINCL value for 225,000 cfs flow.   Figure 5.4.4 graphically depicts the decrease in minimum clearance as the current increases (This graph is only for the regular channel).   It shows that for each 1,000 cfs increase in flow, the average minimum clearance decrease by .065 ft.   Note that the 95% confidence limit gets very close to 0 ft. minimum clearance at 225,000 cfs.   Under regular channel conditions an increase in current significantly reduces the level of safety of operation at the bridge.

5.4.3   Channel Design - We see an even greater difference in minimum clearance values between the modified and regular flow conditions.   Table 5.22, shows a substantial improvement under the modified design.   The mean minimum clearance under modified design is 22.7 feet, 5 feet better than the 17.5' mean for regular channel design.   More significant is the 8 foot improvement over the regular design channel at the same Flow Rate (225,000 cfs).

It is interesting to note that the bridge was hit under the regular channel design, under high flow, using a 5400 horsepower tow.   The value of -9.9 feet indicates that the tow would have hit the bridge 9 feet into the pier, a major collision.   The bridge was hit by the leading edge of the tow on the starboard side, the area most often hit.   This is due to the pilots approach

49

Variable   MINCL   MINIMUM CLEARANCE (FT)

BY   Variable   CURNT   CURRENT

ANALYSIS OF VARIANCE

GROUP	COUNT	MEAN	STANDARD DEVIATION	STANDARD ERROR	MINIMUM	MAXIMUM	95 PCT CONF INTERVAL FOR MEAN	
CURRENT 125	48	20.7658	6.1901	.8935	6.3700	32.0100	18.9684	TO 22.5632
CURRENT 225	95	18.5333	7.9710	.8178	-9.9300	32.7300	16.9095	TO 20.1570
MODIFIED (225)		22.7219					21.067	TO 24.3763
REGULAR (225)		14.25					11.9	TO 16.5
TOTAL	143	19.2827	7.4740	.6250	-9.9300	32.7300	18.0471	TO 20.5182

Table 5.21

COMPARISON OF THE INFLUENCE OF CURRENT

FLOW RATE IN FEET PER SECOND

MINIMUM CLEARANCE

* predicted mean clearance
** 95% confidence boundary for mean clearance
*** 95% confidence boundary for a given observation

LEGEND

□ MINIMUM CLEARANCE

RSq = .181
Int = 28.904
Lin = -0.065
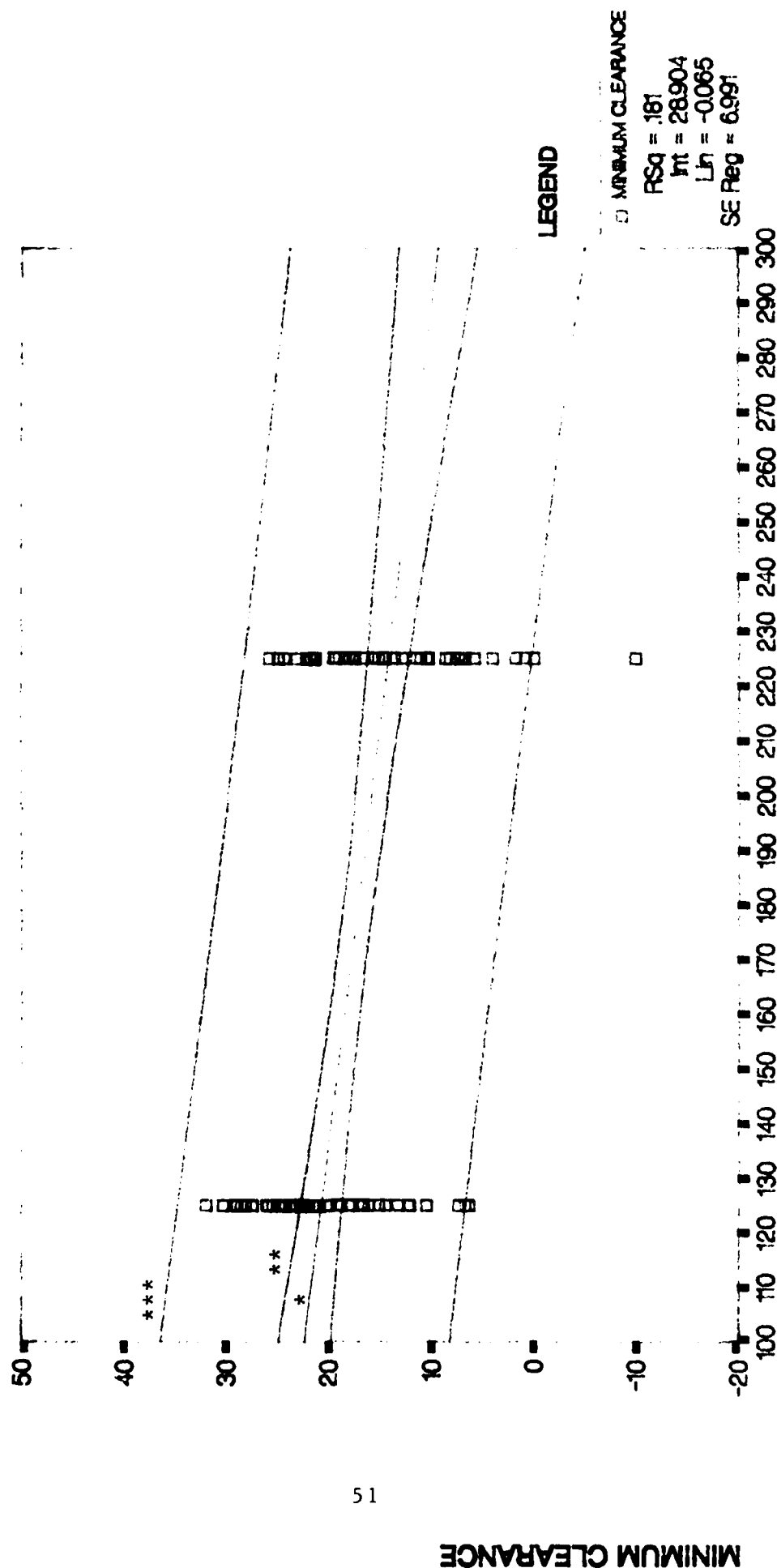SE Reg = 6.991

Figure 5.4.4

51

Variable   MINCL   MINIMUM CLEARANCE (FT)

By   Variable   DESN   CHANNEL DESIGN

ANALYSIS OF VARIANCE

DESIGN	COUNT	MEAN MINCL	STANDARD DEVIATION	STANDARD ERROR	MINIMUM	MAXIMUM	95 PCT CONF INTERVAL FOR MEAN
MODIFIED (225)	48	22.7219	5.6972	.8223	10.6400	32.7300	21.0678 TO 24.3762
REGULAR (125+ 225)	95	17.5449	7.6854	.7885	-9.9300	32.0100	15.9794 TO 19.1105
TOTAL	143	19.2827	7.4740	.6250	-9.9300	32.7300	18.0471 TO 20.5182
REGULAR (225 ONLY)		14.25					11.9 TO 16.5

Table 5.22

to the bridge. In order not to be pushed by the current into the swing span, they approach the bridge very close to the starboard or Iowa side, and try to line up as best as they can with the current. A contributing factor to the performance with the simulation was the lack of information concerning distances that pilots receive under real conditions. On the river, deck hands call off clearance distances to the pilot as he approaches the bridge, telling him how far away he is from the pier. Not having this information available contributed to the difficulty of using the simulator. Therefore the absolute values measured in this study (e.g., minimum clearance) might be considered conservative. Relative values between conditions should not be seriously affected.

5.4.4   In Summary - The difference in the performance involving horsepower is minimal (see Table 5.20) However as mentioned previously some effect was noted under the modified channel condition. Current and channel design have a greater impact on Minimum Clearance values than horsepower. The modified channel produces significantly better results in Minimum Clearance. High flow in the existing channel produces significantly worse values for Minimum Clearance.

5.5   OTHER SAFETY PARAMETERS EXAMINED

5.5.1   Percent Channel Used (PCU) - Percent Channel Used, was also most significantly affected by channel design and current. The modified channel required on the average 85% of the available opening. The regular channel required 4% less or 81%. This difference was explained in 5.2.2. Current also affected the MAX PCU, with the mean value of 83.1% for high flow and 81.8% for low flow. There was no appreciable difference in the PCU values relative to horsepower.

53

5.5.2   Heading - As previously discussed the heading of the tow changed with each scenario. However, once again, channel design and current flow had a more significant effect than horsepower. The minimum and maximum values of heading 249° to 254° were similar to those achieved in the fast time autopilot runs. The lower the heading angle, 249°, the more in line with the current, the higher, the more in line with the bridge opening.

5.5.3   Rudder Angle - Maximum Rudder angle used at the bridge, which can be a measure of control of the tow is significantly affected by the channel design, with the modified design requiring more rudder angle than the regular design. As previously stated, this can probably be attributed to the pilots' unfamiliarity with the modified design conditions.

5.5.4   Speed - As expected current and horsepower were significant factors affecting speed with the high horsepower, high current averaging a maximum speed of over 10 MPH over the bottom and low horsepower low current averaging just over 9 MPH. These results are due to the majority of the pilots using a strategy of getting in shape for the bridge and the using all available HP in order to outrun the current.

5.6 - In summary, current and channel design, at least under the conditions tested were the primary factors contributing to safety of operation at the bridge. The modified channel gave the best overall improvement in the primary safety measure, Minimum Clearance. Even though modified channel produced worse results in some secondary safety measure, the improvement in Minimum Clearance is far more important. We have also shown a corrolation between current and safety at the bridge with the high flow producing less safe results. Though horsepower did not affect performance across the board, we did note some improvement in safety with increased horsepower in conditions unfamiliar to the pilots.

54

6.0 BRIDGE ALTERATION

We have shown that a significant improvement can be made in safety of navigation through the bridge by modifying the channel design. One logical question to ask, assuming the bridge could be changed, is how big should the opening of the bridge be to insure safe navigation. The data collected for this study can be used in this analysis. There are two approaches that can be used. The first is by using a set of design guidelines, in this case, Corp of Engineers Engineering Manual 1110-2-1611, dtd 31 December 1980 entitled "Layout and design of Shallow Draft Waterways". The second method, is to determine what flow rate and HP (scenario) is considered to be a safe operating condition at the bridge, develop a statistical histogram of minimum clearances under these conditions and simply adjust the bridge opening width under other conditions to fit into the limits of the "accepted" safe base line conditions.

6.1 Design Criteria - Paragraph 4-13, Engineering Manual, 1110-2-1611 states

"Clearances - The navigation span (horizontal clearance between piers) should be somewhat greater than the designed width of the channel in the reach depending on the alignment and velocity of currents in the reach, alignment of the channel approaching the bridge, particularly from upstream, and the probable effect of the prevailing winds."

Since design of a bridge opening should be somewhat greater than the channel design width, we next need to determine the channel design width.

In this case we will assume a straight reach with one way traffic through the bridge. Paragraph 4-5 in EM 1110-2-1611 states

"Operating experience has indicated that the minimum clearance required for reasonably safe navigation in straight reaches should be at least 20 ft. between tow and channel limits for two-way traffic, 40 feet for one way traffic, and at least 50 feet between tows when passing." It goes on to say "Also, additional clearance should be provided in channels with restricted cross-sectional area or where adverse currents would be encountered".

The guidance in paragraph 4-5 given for minimum width of a channel for one way traffic for a 105 ft wide tow is 185 ft.

As seen in Figure 2.1 of this report the effective width between piers is only 181 feet, four feet _less_ than minimum requirements. We have also shown that under all of the scenarios tested, the mean minimum clearance falls well under the 40 feet required by one way traffic, and in the high flow conditions the mean minimum clearance falls under the 20 ft. design criteria for two way traffic.

The final step is to determine how wide the bridge opening should be. The best approach is to use the Percent Channel Used. To determine the design width we take the worst case Maximum Percent Used figure and multiply it by the effective width of the span to determine the maximum area used by the Tow in feet. In our study the worst regular channel design max PCU figure was 82.75% for the 5400 HP Tow operating in 125,000 cfs flow. Therefore our Tow used .8275X181 ft or 150 feet of the span. Since the design criteria for oneway traffic calls for 40 ft clearance on either side we simply add the required clearance to the max PCU value to determine the design or required width. Thus, the _optimal design width_ is 150' + 40' + 40', or _230 feet, 49 feet more than the existing opening_.

A more conservative approach would be to use the design minimum clearance for two way traffic. Following the same procedure above the optimal design width based on two way traffic criteria is 150 ft + 20 + 20, or 190 feet, 9 feet more than the existing opening. In both cases crab angle effect is not accounted for.

In summary we see that in order to meet minimum design guidance in EM 1110-2-1611 an effective _bridge opening_ anywhere _from_ 190 to 230 _feet is required_. It is emphasized that conditions at Fort Madison Bridge, especially due to the cross current, probably require more than these minimum design clearances.

57

6.2 Histogram - The data for an analysis based on a Histograms is also

available. It would be necessay for the appropriate agencies to determine what

existing conditions at Fort Madison Bridge are considered acceptable, or safe

before an analysis based on histograms can be used. Once this baseline has been

established an analysis based on statistical histogram is possible in order to

determine either operating limits or bridge opening requirements. For example,

lets suppose that the Coast Guard and River Industry were to state that the

conditions of operating a 5400 HP Tow in a flow of 125,000 cfs were accepted as

"safe" operating conditions at the bridge. We have developed a histogram of

minimum clearances for this scenario with 2.5% limits. It is then possible to

adjust bridge opening widths to insure the histograms developed for all other

scenario would fall within the same minimum clearances boundaries as the base

line or "safe" condition.

7.0 SUBJECTIVE EVALUATION

In addition to the objective evaluation based on quantitative data which was described previously, a subjective evaluation, based on data collected from pilot ratings, was also conducted. This evaluation is described below.

7.1   Pilot Ratings - During the study, the pilots were requested to subjectively evaluate each run. The questions asked were:

o "On a collision danger scale of 1 to 10, 10 being extremely dangerous or actually collided, how would you score this run? What features contributed to the danger/lack of danger?"

o "On a realism scale of 1 to 10, 10 being precisely like actual runs at Ft. Madison, how would you score the realism of this run? What particularly made this run realistic/unrealistic?"

The results of their evaluations is located in Annex C.

In our analysis of the pilots' scores, we were not only interested in the pilots' rating by scenario, but how the pilots' compared among themselves and how the pilots' ratings of difficulty, realism and danger compared with the values of horsepower, channel design, current, replication, and pilot number.

7.1.1   Difficulty - As expected, the pilots' ratings were different with

pilots 9 and 10 giving very low scores of 1.6 and pilot 5 and 6 giving higher

scores but still relatively low scores of 4.2. This indicates that across the

board the pilots did not consider the runs difficult. There may be certain

situations they found more difficult than others. When difficulty is tested

against horsepower, channel design, current and replication the scores do not

appear significantly different. The low horsepower, high flow, and modified

channel averaged a difficulty rating from less than 1 point to a little over 1

point more difficult than their counterparts. The statistical figures indicate

that pilot number has the greatest effect on the difficulty rating with the flow

rate also having some affect. Because each pilot had his own subjective opinion

scale it is not surprising that pilot number would have a significant affect.

It is important to note that flow rate did have a significant affect, though

less than pilot number, on the pilot's subjective ratings. They found the high

flow conditions more difficult.

7.1.2   Danger - We see the same trend in the danger rating with again

relatively low scores. Here pilot number and current have the greatest affect

on the scores with high current being rated more dangerous than low current, but

still with a relatively low score of 3.13. In the case where the pilot hit the

bridge his stated reason was a combination of high flow and getting in "too

deep" towards the right hand pier.

60

7.1.3   The final analysis was done on the pilot's ratings of how

realistic he thought the system was. Here we see only the pilot's subjectivity

as the major variable affecting the scores. The relatively high score average

of 7.08 would have been 8.07 had pilot number 6 not been included. This

indicates that the pilots thought that the system was fairly realistic.

7.2   Final Subjective Ratings - Each pilot was given a final debriefing

and requested to answer the following questions:

     o "On a scale of 1 to 10, with 10 being precisely equivalent to

the real boat, please rate the tow boat handling characteristics in the

cnannel. What problem, if any, did you note and how severe were they?"

     o On a scale of 1 to 10, 10 being exactly realistic, please rate

the current effects as simulated. What problems, if any, and how severe?

     o On a scale of 1 to 10, 10 being exactly as on the river itself,

please rate your tow's handling going past the bridge. What problems, if any,

did you observe and how severe were they?

     o On a scale of 1 to 10, 10 containing all information useful for

navigation but no unrealistic or excessive information, please rate the visual

scene. Any problems? How severe?

     o Please rate the tow boat control station on a scale of 1 to 10,

10 being precisely realistic. Any problems? How severe?

o   Were you able to adapt to the simulator so that your responses were the same as they would be or the river? Comments.

o   Was the familiarization adequate?

o   How many runs did you make after the familiarization before you felt comfortable and proficient with the simulator?

o   What changes would you like to see to make this simulator a more realistic or useful research tool?

o   Do you feel a simulator like this could be useful in training tow boat operators? Comments.

o   What would be the best type of material to teach on the simulator?

o   Tow boat handling, generally

o   Rules of the Road

o   Local area familiarization

o   Instruments and procedures

o   Night navigation

o   Locking, docking and fleeting

o   All of the above

o   None of the above

We also asked the pilots for comments on the currents and their strategy as well as any general comments.

7.2.1   Debriefing results - Listed in Table 7.1 is a matrix of the pilots final ratings:

As you can see, the high ratings given by the pilots, indicate they all considered the simulator, the modelled performance and the currents to be realistic. They all considered the tow simulator to be a useful training tool.

Table 7.1 (part 1)

Pilot	Handling	Current Handling	Tow in Current	Visual Scene Bridge	Control Station	Adaptability	Familiarzation	No Runs Required/ Familiarize	Training Familiarize
5	8	9	9	7	10	Y	Y	3	Y
6	7	8	8	7	9	N	Y	3	Y
9	8	10	8	10	10	Y	Y	5	Y
10	10	8	8	9	10	Y	Y	2	Y
	8.25	8.75	8.25	8.25	9.75	Y	Y	3.25	Y

Table 7.1 (part 2)

Pilot #	Handling	Rules of Road	Local area Familiarization	Instruments Navigation	Night	Locking, Docking, Fleeting
5	N	N	Y	Y	N	N
6	Y	Y	Y	Y	Y	Y
9	Y	Y	Y	Y	Y	Y
10	Y	Y	N	Y	Y	Y

Table 7.1

8.0 CONCLUSIONS

Several conclusions can be drawn from this study. They involve further validation of the usefulness and accuracy of the simulator as well as the primary purpose of safety improvement at the bridge.

8.1   Safety at the Bridge - As far as the primary purpose of this study, improved safety of operation at Ft. Madison, the following conclusions can be made.

o Based on historical data and the results of this study, it appears that under the conditions tested, Ft. Madison Bridge does pose a higher risk than is acceptable to <u>experienced</u> pilots with a knowledge of local conditions. Pilot knowledge of the area is extremely important and contributes to safety of operation at the bridge. Since all pilots in this study were very able, experienced pilots no conclusion can be reached concerning pilot ability.

o   Of all of the factors we tested which affect and detract from safety of operation the primary contributing factors are high flow and the design of the channel. In the case of regular design, the left hand set encountered at the bridge poses the greatest problem. Though Horsepower does not appear to have any major affect under the conditions tested or in cases where emergency maneuvering is not required, we have shown some correlation to HP and safety with an increase in the margin safety as Horsepower increases. In general the margin of safety decreases as flow increases and the margin of safety increases as HP increases.

o   The safest conditions at the bridge exist under low flow condition, or the modified channel. Both of the low flow, regular design minimum clearance values were 6 to 8 feet better than each high flow condition. The minimum clearance values for each of the modified channel scenarios were 6 to 11 feet better than each of the high flow regular design scenarios, and up to 3 feet better than the low flow scenarios. The best MINCL values were obtained in the modified channel.

o   Based on the results of this study, under the conditions tested and on criteria found in EM 1110-2-1611 the <u>navigation span opening is not adequate</u> for this size barge and should be anywhere from 9 ft. to 49 ft. wider. This finding should be considered in any program undertaken to improve safety of operation at the bridge.

o   Pilot knowledge of the area and pilot ability appear to be a major factor in safety of operation at the bridge.

8.2   Simulator: It appears that the ship maneuvering simulator tow accurately and correctly simulates conditions at Ft. Madison Bridge as well as tow boat handling characteristics.   There is room for improvement and each of the pilots' comments are valid. However, for the purposes of this study we can conclude that under the conditions studied the <u>simulator realistically portrayed events as they actually would occur at Ft. Madison.</u>

The simulator has been judged by the experienced river pilots who participated in this test to be a valuable training device.   It is also a valuable analytical device as can be seen by the data obtained from this test.

9.0 RECOMMENDATION

The final recommendations of this report are:

      o Second Coast Guard District and River Industry use results of this study to aid in improving safety at Ft. Madison Bridge.

      o Based on the results of this study, under the conditions tested it appears that dredging behind Dutchman's Island would promote safety at the bridge. The Coast Guard in conjunction with the Corps of Engineers conduct further investigation into the feasibility and costs of dredging behind Dutchman's Island. Further tests may also be conducted on the dike alternative to prove or refute subjective analysis done in conjunction with this test.

      o The Coast Guard investigate further the need for alteration of the navigation span at Ft. Madison Bridge. Bridge alteration to enlarge the navigation span would promote safety at the bridge.

      o Upgrade tow simulator and include information for pilots on necessary landmarks and visual aids necessary for any further test. This may also be helpful, particularly if the dike alternative is nearly as effective as the dredged alternative but has a lower life cycle cost.

      o Continue testing of other unsafe bridges, with St. Louis Harbor being next.

      o Coast Guard, in conjunction with appropriate agencies should determine criteria for allowable minimum clearance or percent channel used considered to be safe.

      o Coast Guard investigate the use of simulation in bridge design and permitting procedures.

REFERENCES

U.S. Army Corps of Engineers Engineering Manual, EM 1110-2-1611 Layout and Design of Shallow - Draft Waterways, 31 December 1980.

Hydrographic Survey, Ft. Madison Bridge, U. S. Geological Survey, 28 June 1984.

Coast Guard Report #D-77-76 "Analysis of Bridge Collision Incidents."

Draft U. S. Coast Guard Report "Mississippi River Casualty analysis for the Years 1981 - 1983."

Norusis, Marisa, SPSS-X Advanced Statistics Guide, McGraw Hill, 1985

SPSS-X Statistical Package, Version 2.1., Computer Program.

SPSS Graphics Computer Program.

"Estimation of Hydrodynamic Maneuvering Models for Six and Fifteen Barge River Tows" U. S. Coast Guard Technical Report 83011-1, prepared by Hydronautics, Inc.
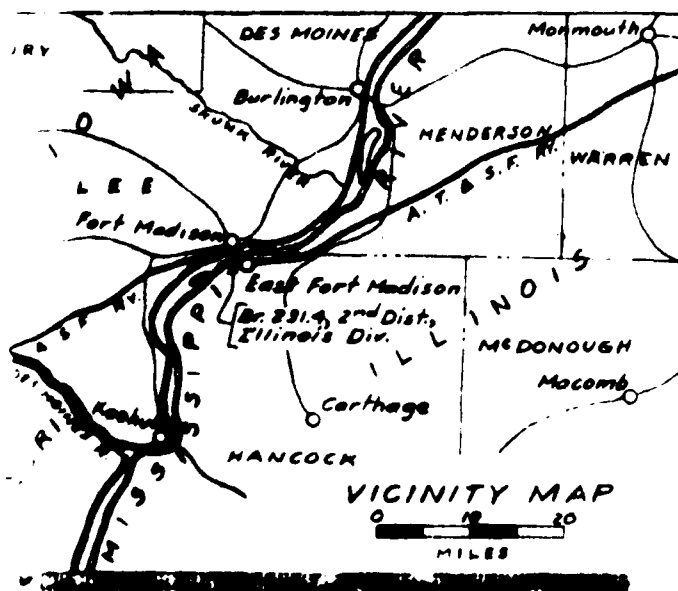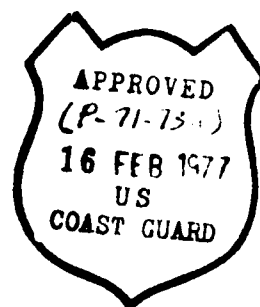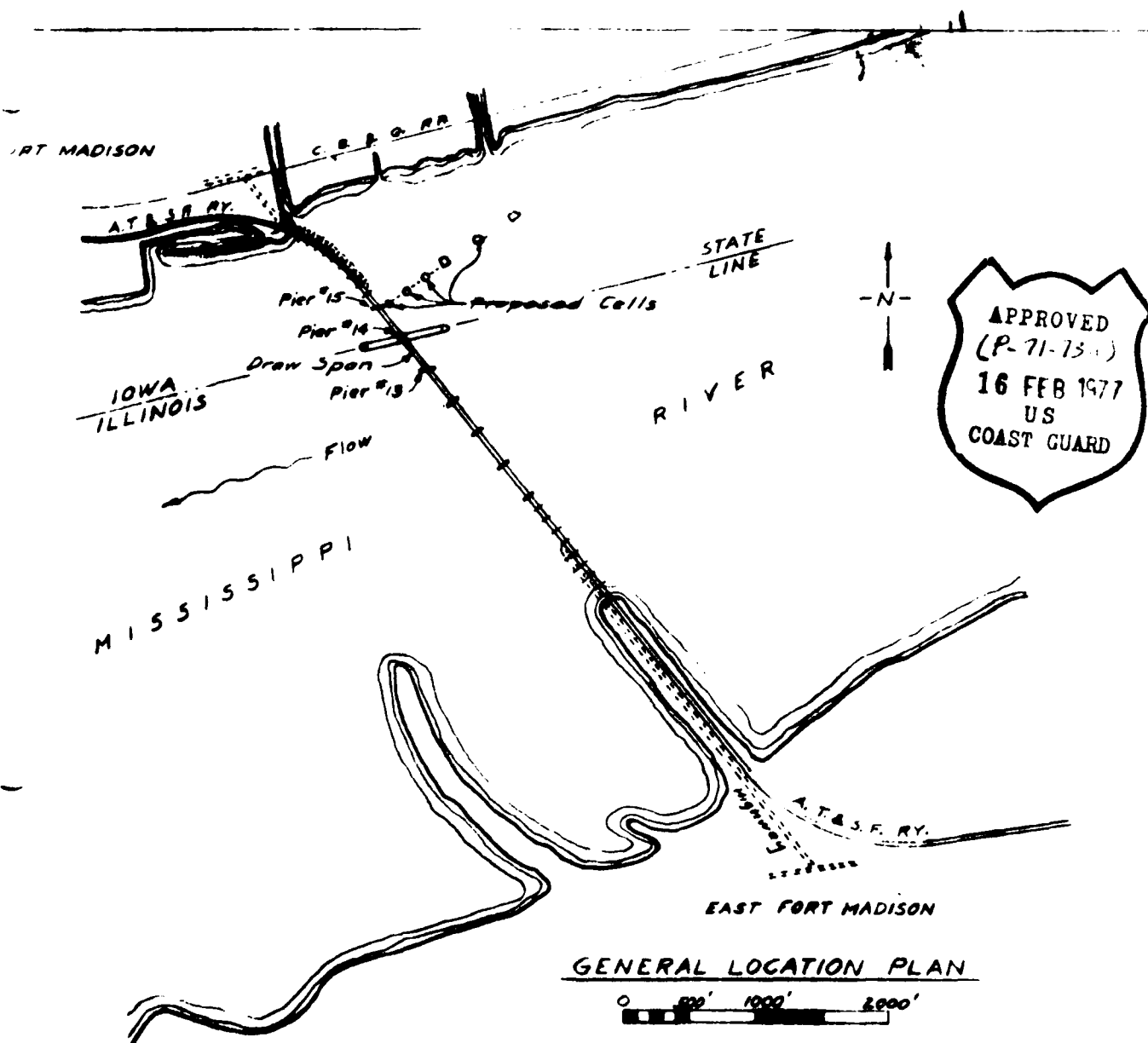
Hatton, Ankudinov, Barr
U. S. Coast Report CG-D+10-84, "Model Tests and Computer Simulations of a 15 - Barge Tow for the Upper Mississippi River", Tracor Hydronautics, Inc., Jan 1984.

Appendices

Appendix A

Bridge and River Characteristics

RT MADISON

C.B.&Q. RR.
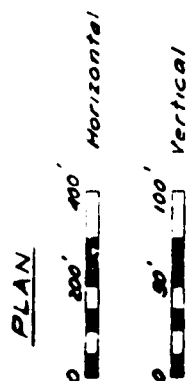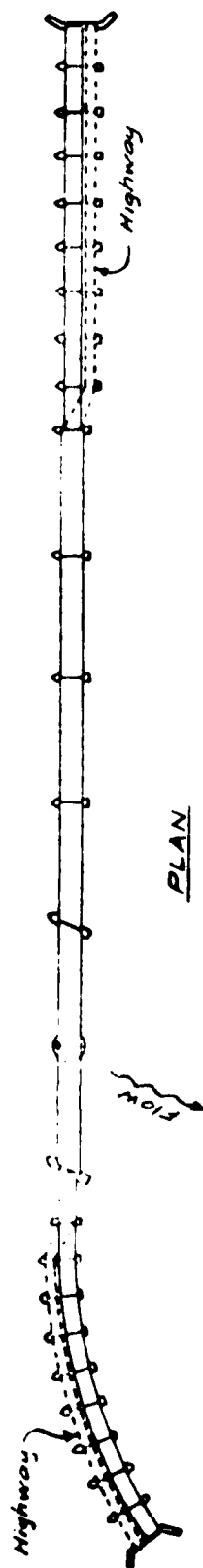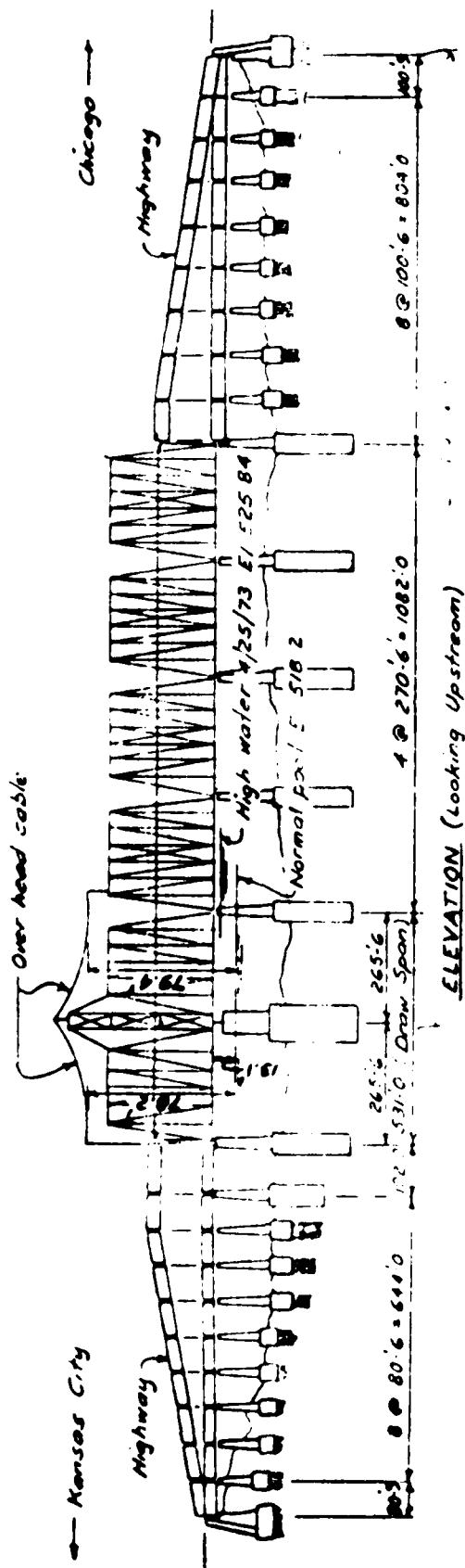
A.T.&.S.F. RY.

STATE LINE

Pier º15

Proposed Cells

Pier º14

Draw Span

IOWA
ILLINOIS

Pier º13

Flow

R I V E R

-N-

M I S S I S S I P P I

A.T.&.S.F. RY.

EAST FORT MADISON

GENERAL LOCATION PLAN

0   500'   1000'   2000'

VICINITY MAP

DES MOINES

Monmouth

Burlington

HENDERSON

WARREN

L E E

A.T.&.S.F. RY.

Fort Madison

East Fort Madison

Br. 231.4, 2nd Dist,
Illinois Div.

I L L I N O I S

McDONOUGH

Macomb

Carthage

HANCOCK

Keokuk

M I S S I S S I P P I

0   10   20
MILES

"As Built" 10/76

B.E.S. 5310

THE A. T. &. S. F. RY. SYSTEM

BR. 231.4, SECOND DIST., ILLINOIS DIV.

AT

MILE 383.9, UPPER MISSISSIPPI RIVER

PROPOSED 25'-5½ SHEET PILE CELLS

SCALE: AS NOTED   CHICAGO, ILL., MAR. ,1973
OFFICE OF BRIDGE ENGINEER SYSTEM
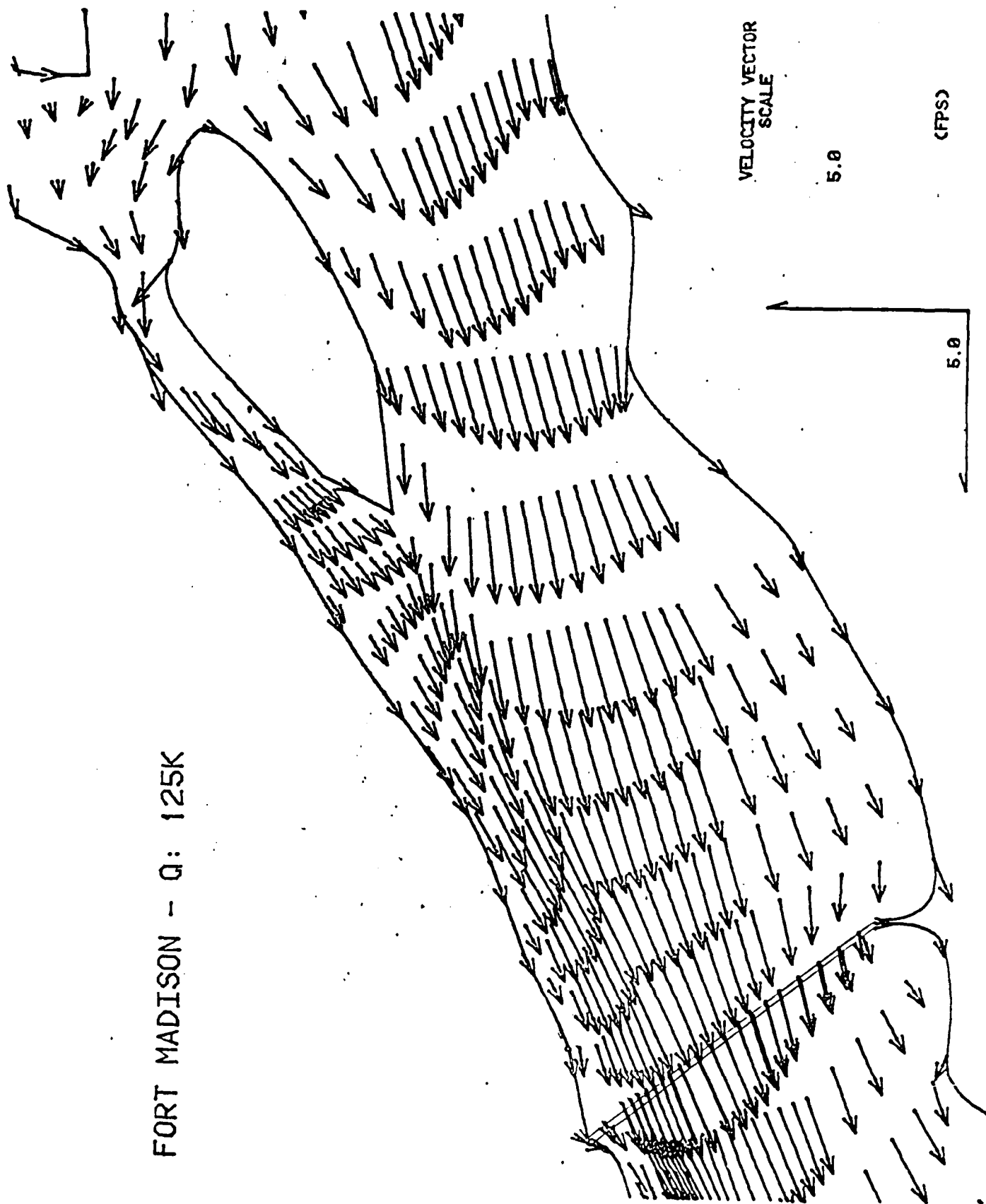
Revised 5/73   SHEET 1 OF 3

A-1

ELEVATION (Looking Upstream)

PLAN

Note: Elevations based on Mean Sea Level Datum.
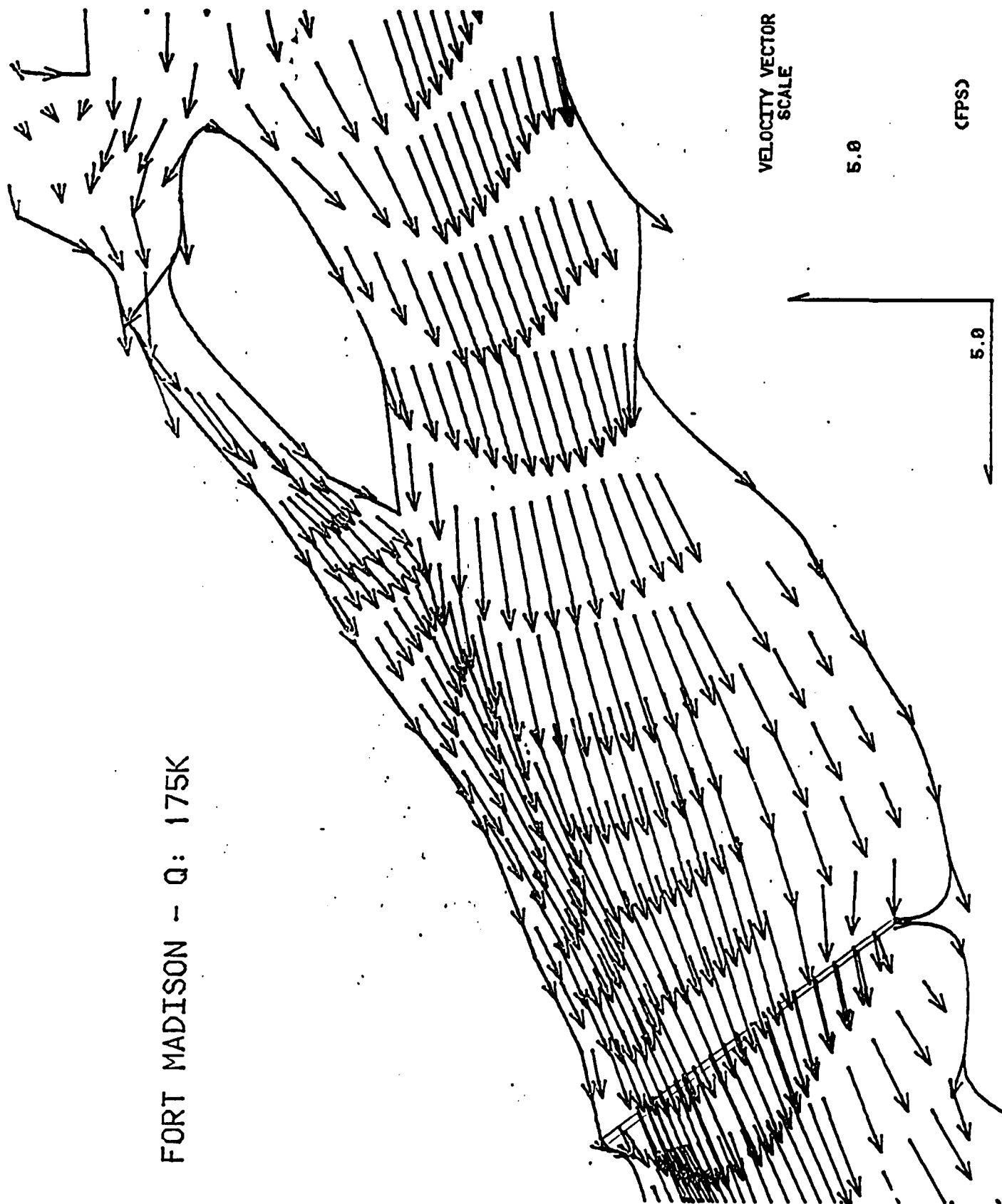
B.E.S. 5310

THE A.T. &. S.F. RY. SYSTEM

BR. 231.4, SECOND DIST., ILLINOIS DIV.

AT

MILE 383.9, UPPER MISSISSIPPI RIVER

PLAN AND ELEVATION

SCALE: AS NOTED   CHICAGO, ILL., MAY, 1973
OFFICE OF BRIDGE ENGINEER SYSTEM

SHEET 3 OF 3

APPROVED
8 AUG 1973
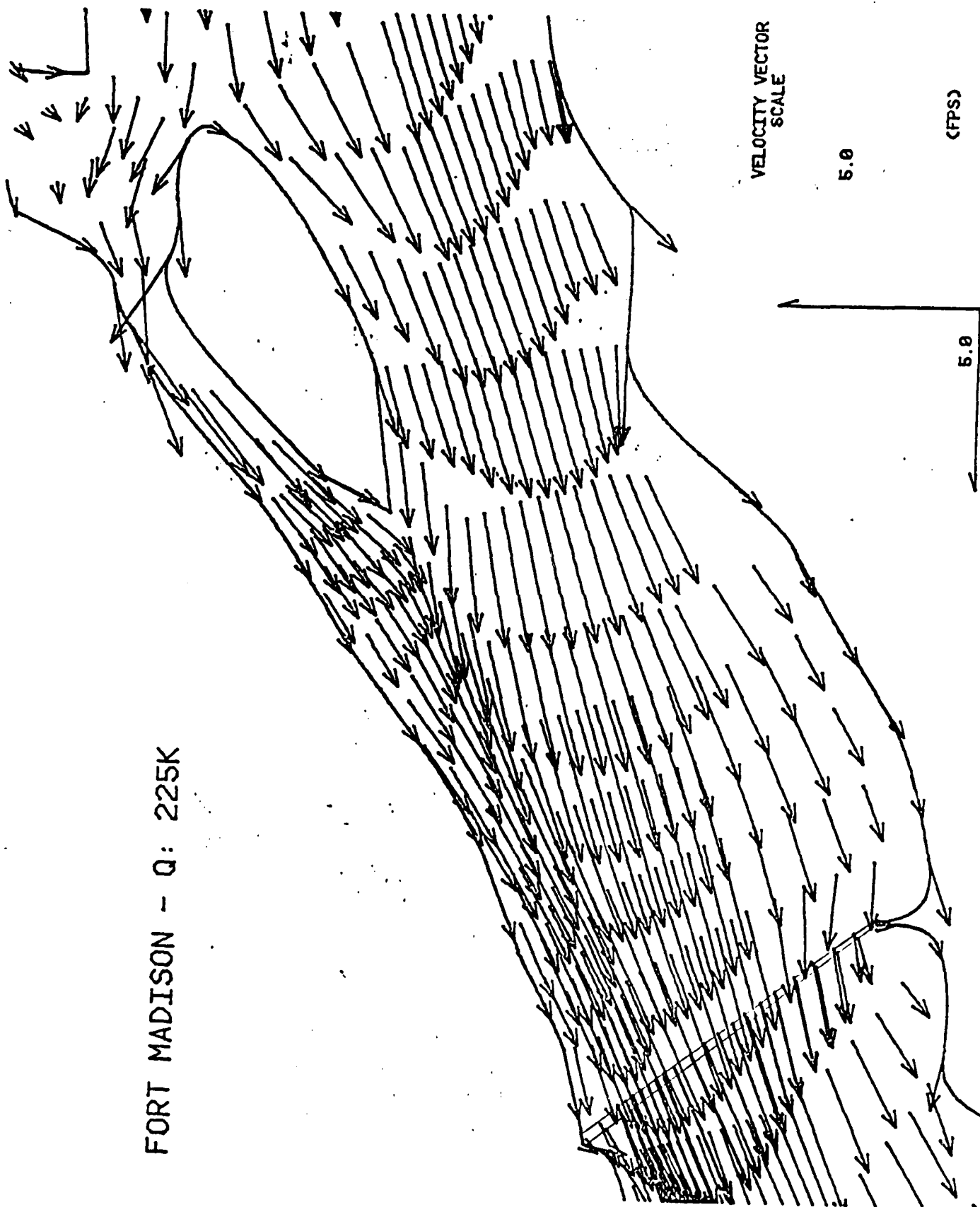U.S.
COAST GUARD

A-2

FORT MADISON – Q: 125K

VELOCITY VECTOR
SCALE

5.0

(FPS)

5.0

FORT MADISON — Q: 175K

VELOCITY VECTOR
SCALE

5.0

(FPS)

5.0

FORT MADISON - Q: 225K

VELOCITY VECTOR
SCALE

5.0

(FPS)

5.0

A-5
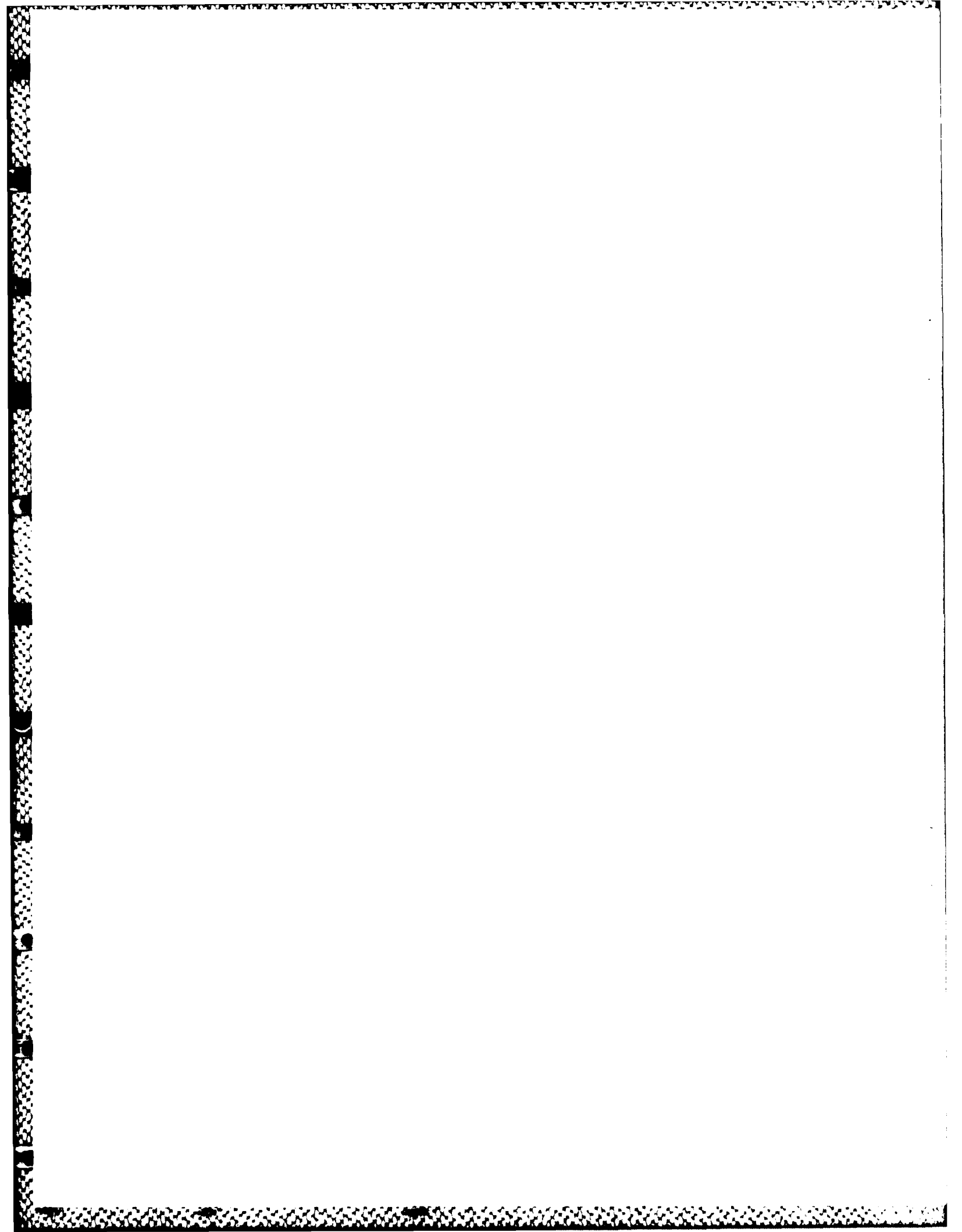
Appendix B

Scenario Data

WATSON BRIDGE STUDY
M/W VAR SIMULATOR

DEC VAX-11/730 VMS V4.1

AGGREGATED FILE

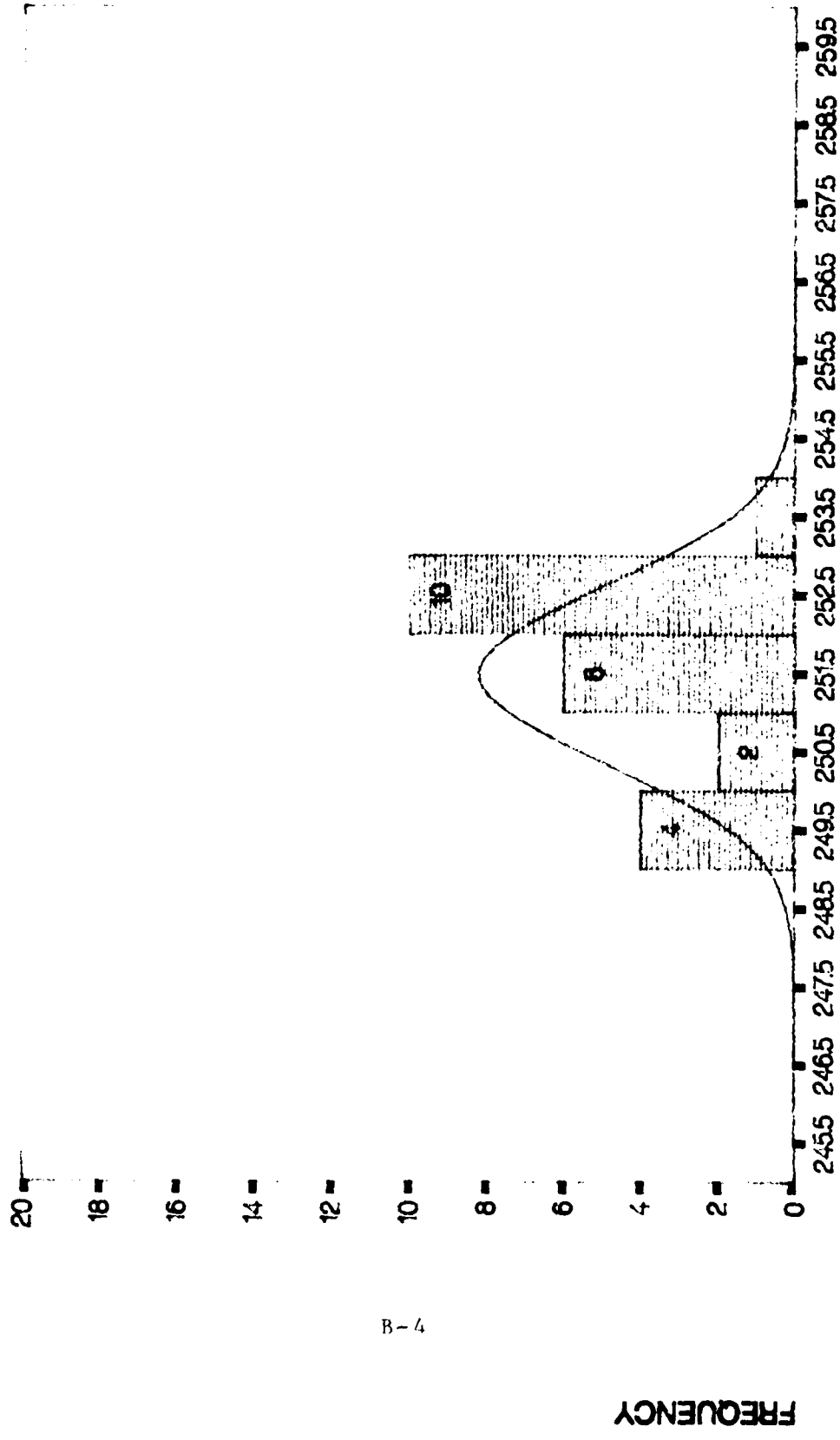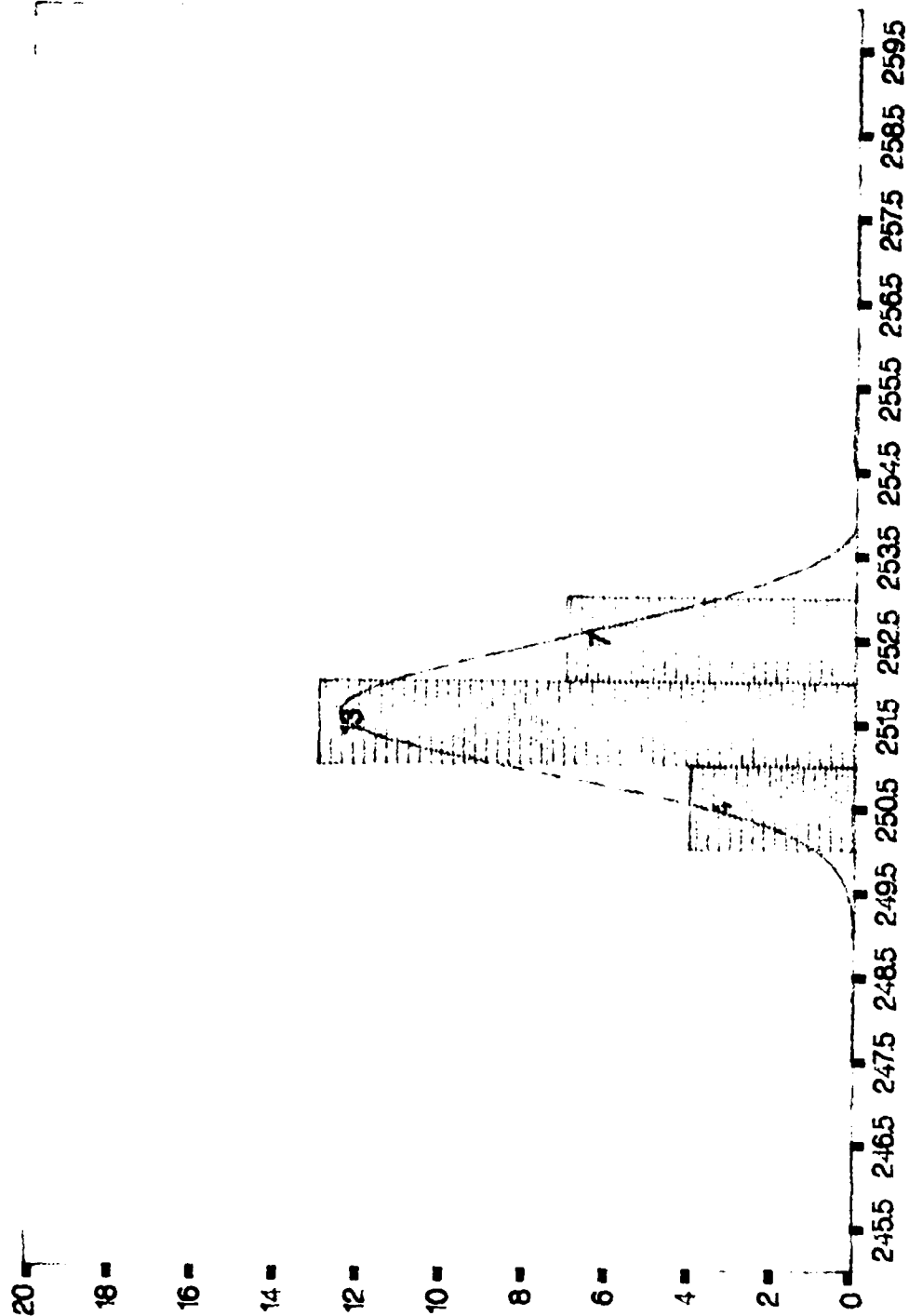| OBS	SESN	MINTC	MINRMS	MINCLE	MINCLS	MAXRPM	MAXSPEED	MAXROL	MAXBEANS	AVERPM	ALEODANS	AZOLSEC

MINIMUM HEADING THROUGH BRIDGE
225K CFS - 5400 HP

LEGEND

Std. Dev. = 108
Mean = 2515
N = 23

FREQUENCY

MINIMUM HEADING (DEGREES)

B-4

MINIMUM HEADING THROUGH BRIDGE
225K CFS - 3900 HP

FREQUENCY

MINIMUM HEADING (DEGREES)

LEGEND

Std Dev. = 69
Mean = 2517
N = 24

B - 5

MINIMUM HEADING THROUGH BRIDGE
125K CFS - 3900 HP
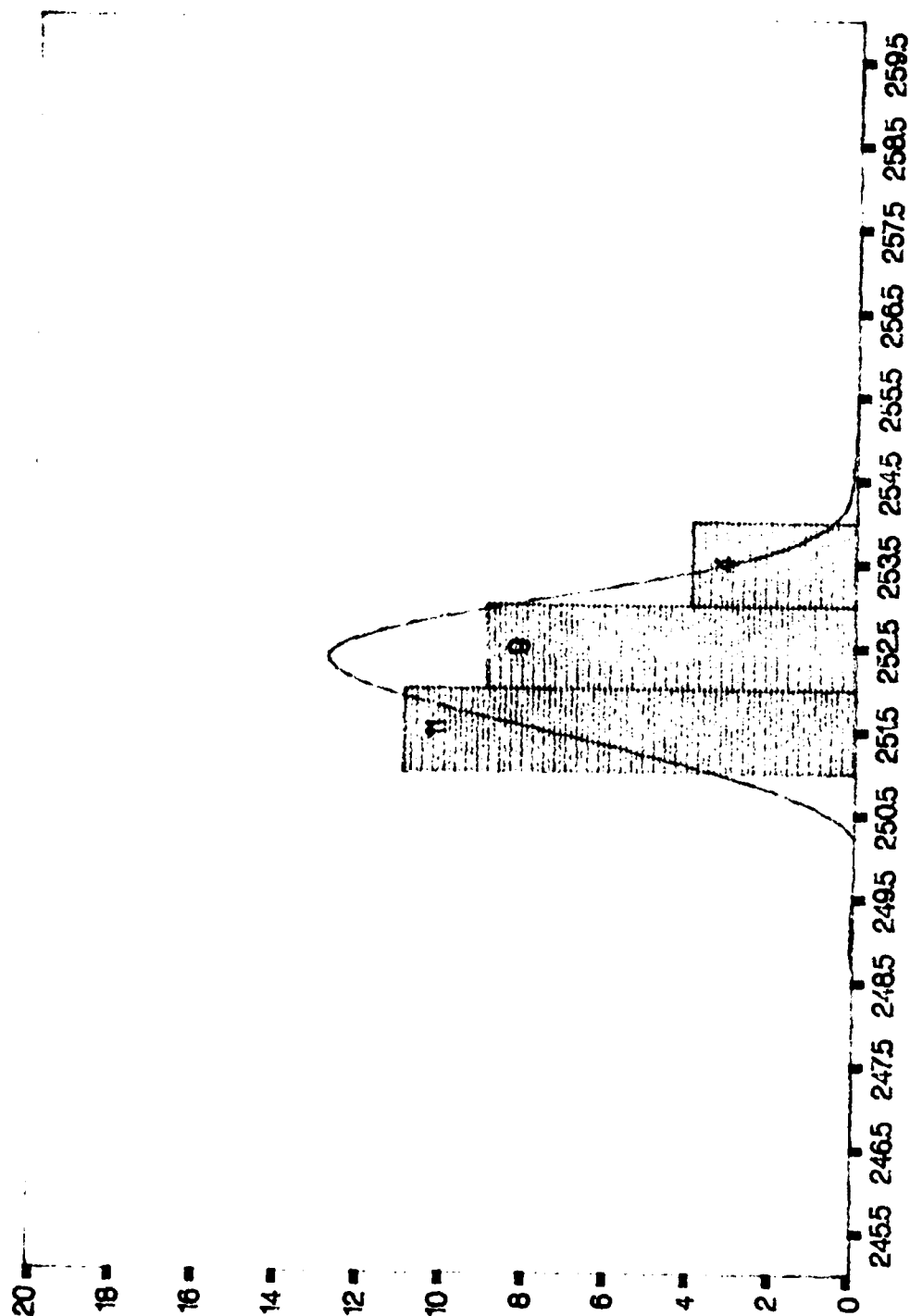
LEGEND

Std. Dev. = .66
Mean = 252.3
N = 24

FREQUENCY axis: 0, 2, 4, 6, 8, 10, 12, 14, 16, 18, 20

MINIMUM HEADING (DEGREES): 245.5 246.5 247.5 248.5 249.5 250.5 251.5 252.5 253.5 254.5 255.5 256.5 257.5 258.5 259.5

MINIMUM HEADING (DEGREES)

B - 6

MINIMUM HEADING THROUGH BRIDGE
125K CFS - 5400 HP

FREQUENCY

20
18
16
14
12
10
8
6
4
2
0

245.5 246.5 247.5 248.5 249.5 250.5 251.5 252.5 253.5 254.5 255.5 256.5 257.5 258.5 259.5

MINIMUM HEADING (DEGREES)
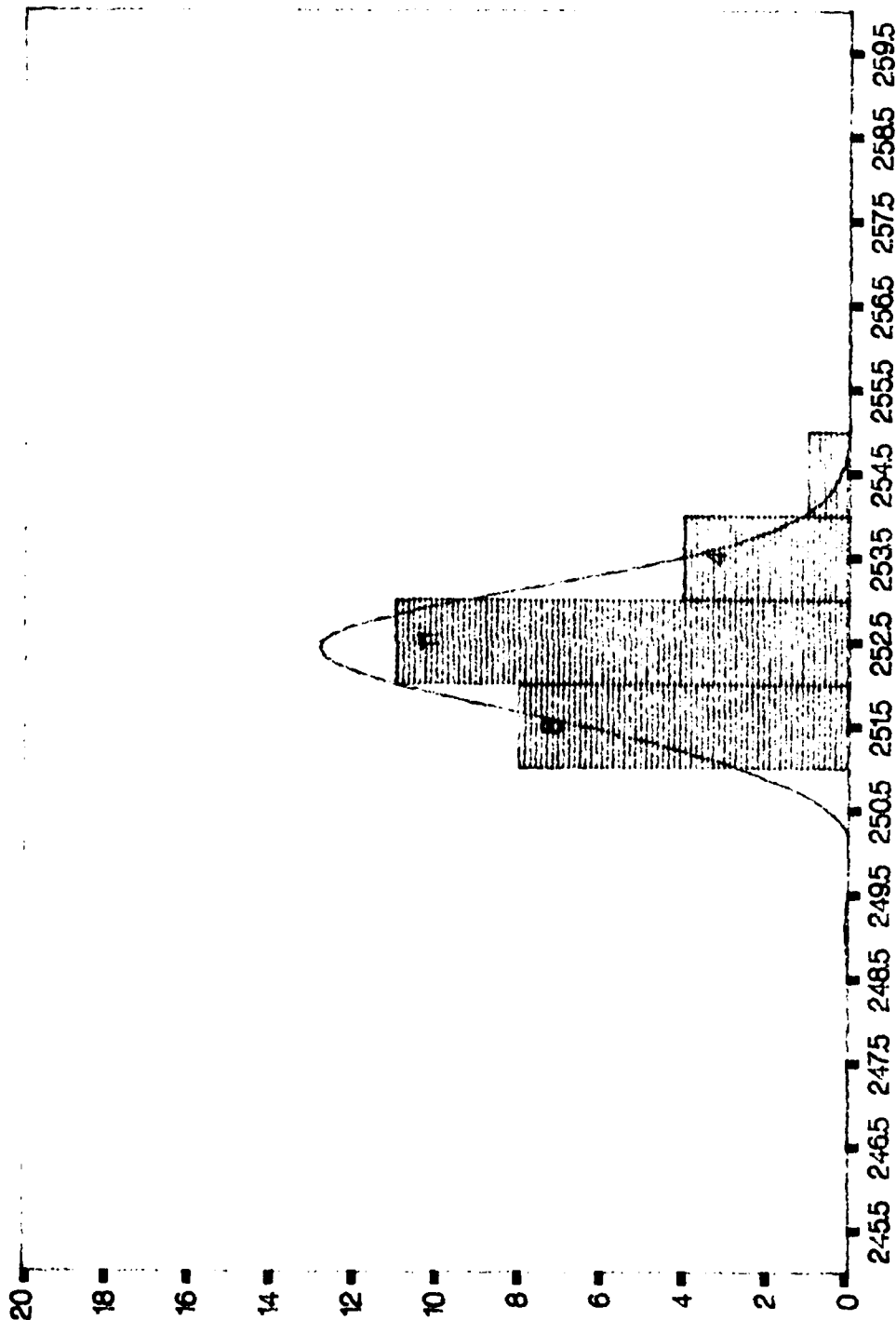
LEGEND

Std. Dev. = .68
Mean = 252.4
N = 24

B-7

MINIMUM HEADING THROUGH BRIDGE
225K CFS - 3900 HP MODIFIED

LEGEND

Std Dev = 107
Mean = 2527
N = 24
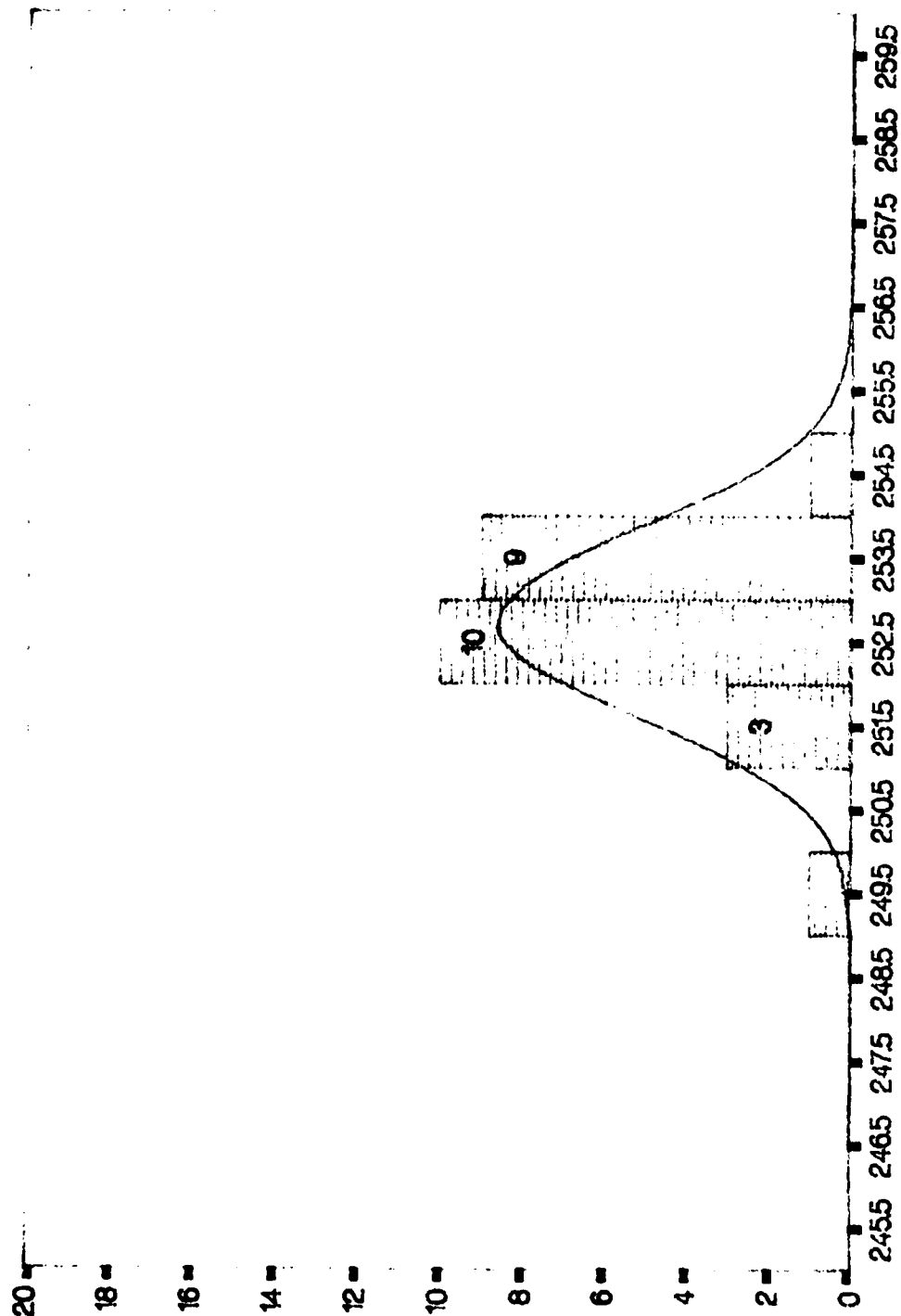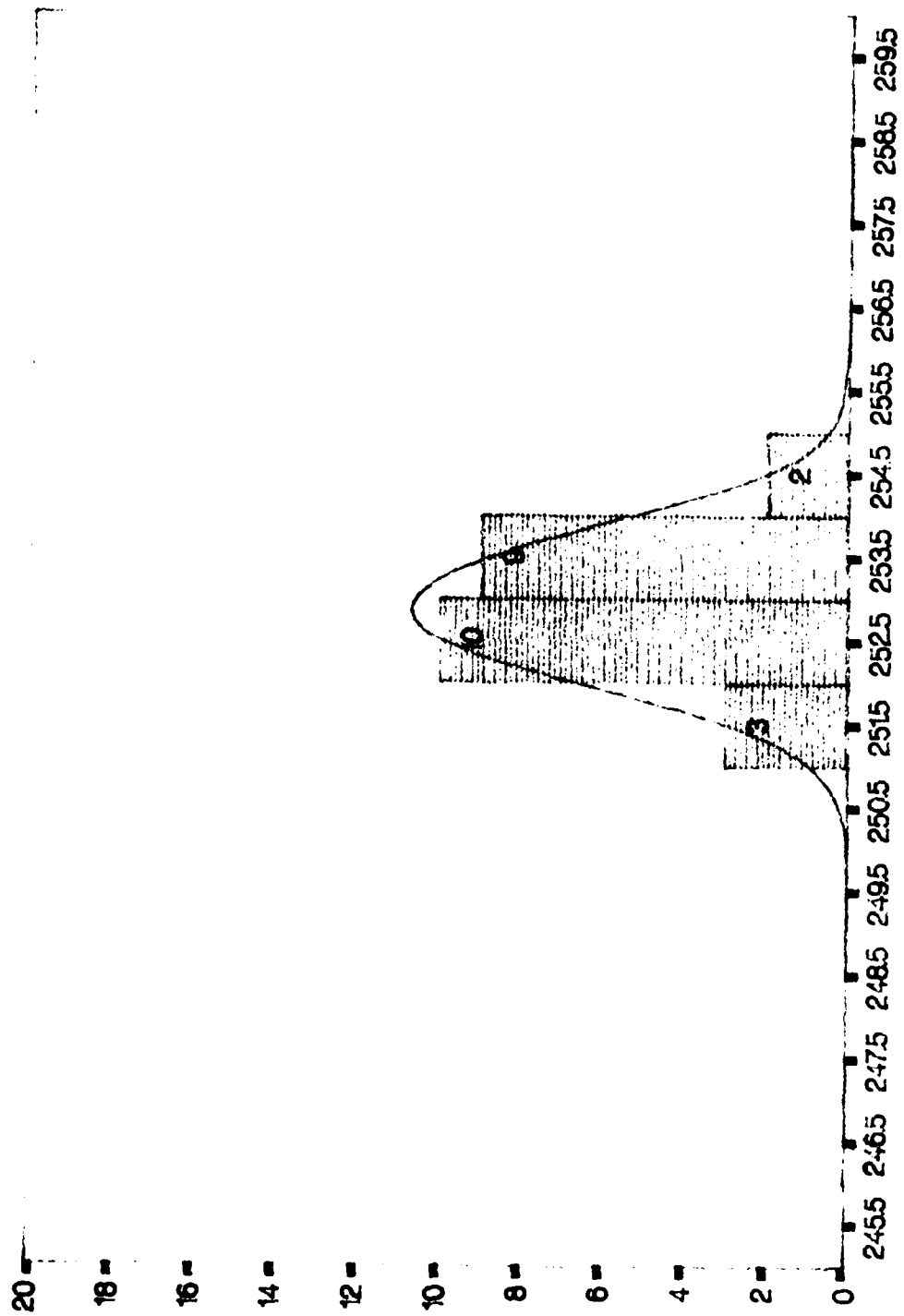
MINIMUM HEADING (DEGREES)

FREQUENCY

B-8

MINIMUM HEADING THROUGH BRIDGE
225K CFS - 5400 HP MODIFIED

LEGEND

Std. Dev. = 81
Mean = 2529
N = 24

FREQUENCY

20
18
16
14
12
10
8
6
4
2
0

2455 2465 2475 2485 2495 2505 2515 2525 2535 2545 2555 2565 2575 2585 2595

MINIMUM HEADING (DEGREES)

MAXIMUM WIDTH USED
1250 CFS - 5400 HP

MAXIMUM WIDTH USED (FEET)

FREQUENCY

B-10

MAXIMUM WIDTH USED
225K CFS - 5400 HP

MAXIMUM WIDTH USED (FEET)

FREQUENCY

LEGEND

Std Dev. = 10.03
Mean = 139
N = 23
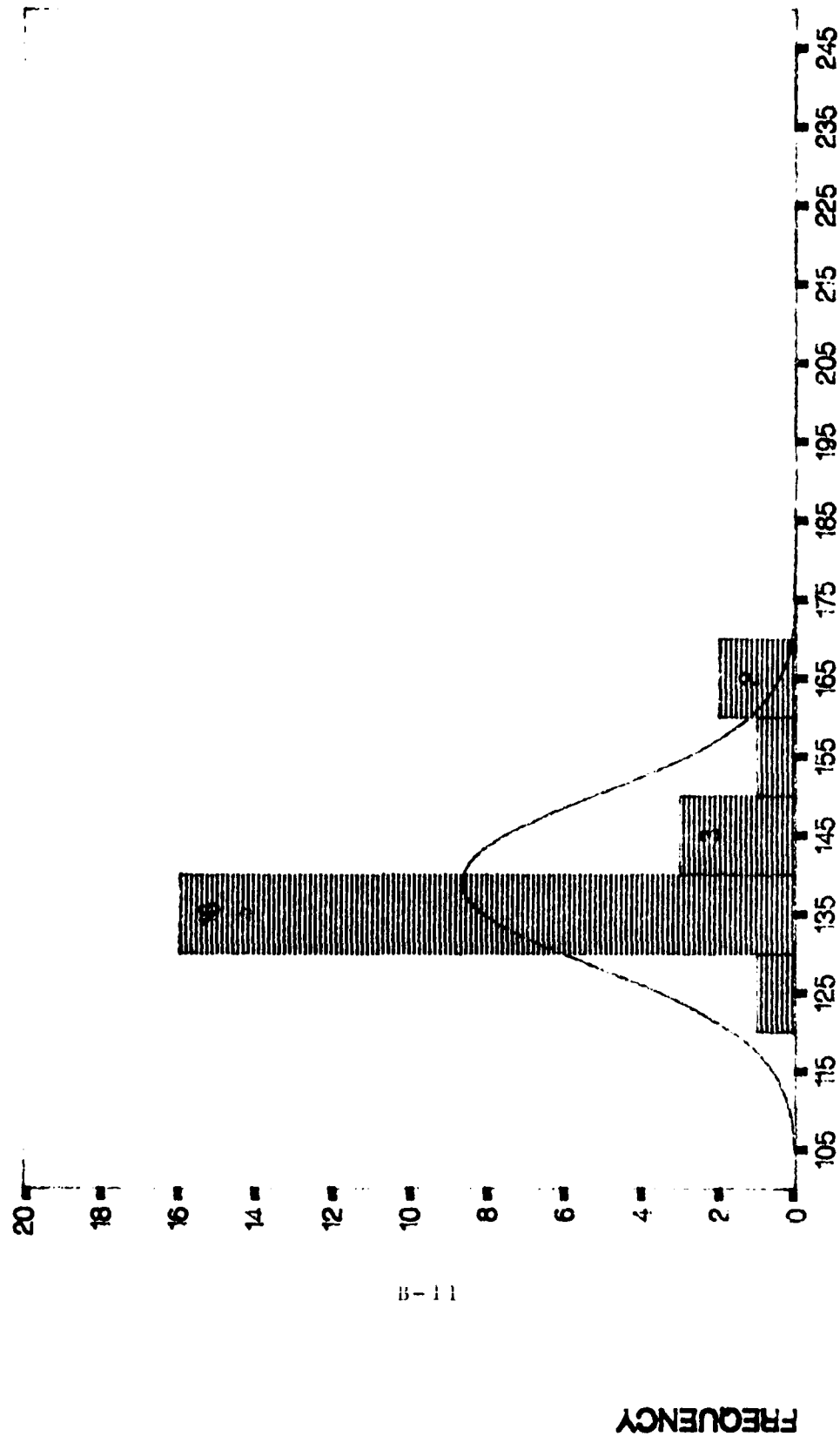
MAXIMUM WIDTH USED
225K - 5400 HP MODIFIED

FREQUENCY (vertical axis): 0, 2, 4, 6, 8, 10, 12, 14, 16, 18, 20

MAXIMUM WIDTH USED (FEET) (horizontal axis): 105, 115, 125, 135, 145, 155, 165, 175, 185, 195, 205, 215, 225, 235, 245

B-12
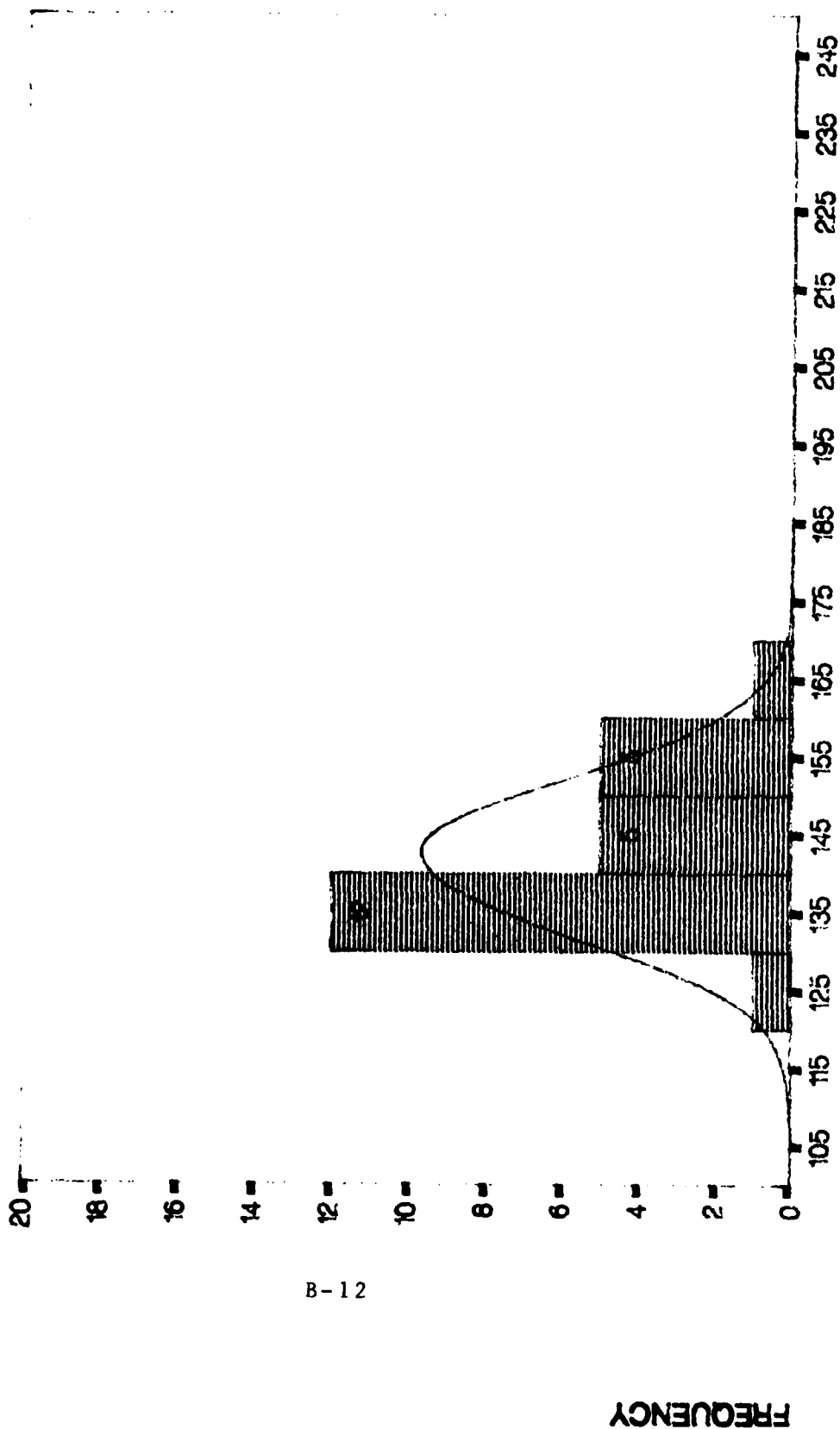
MAXIMUM WIDTH USED
125K CFS - 3900 HP
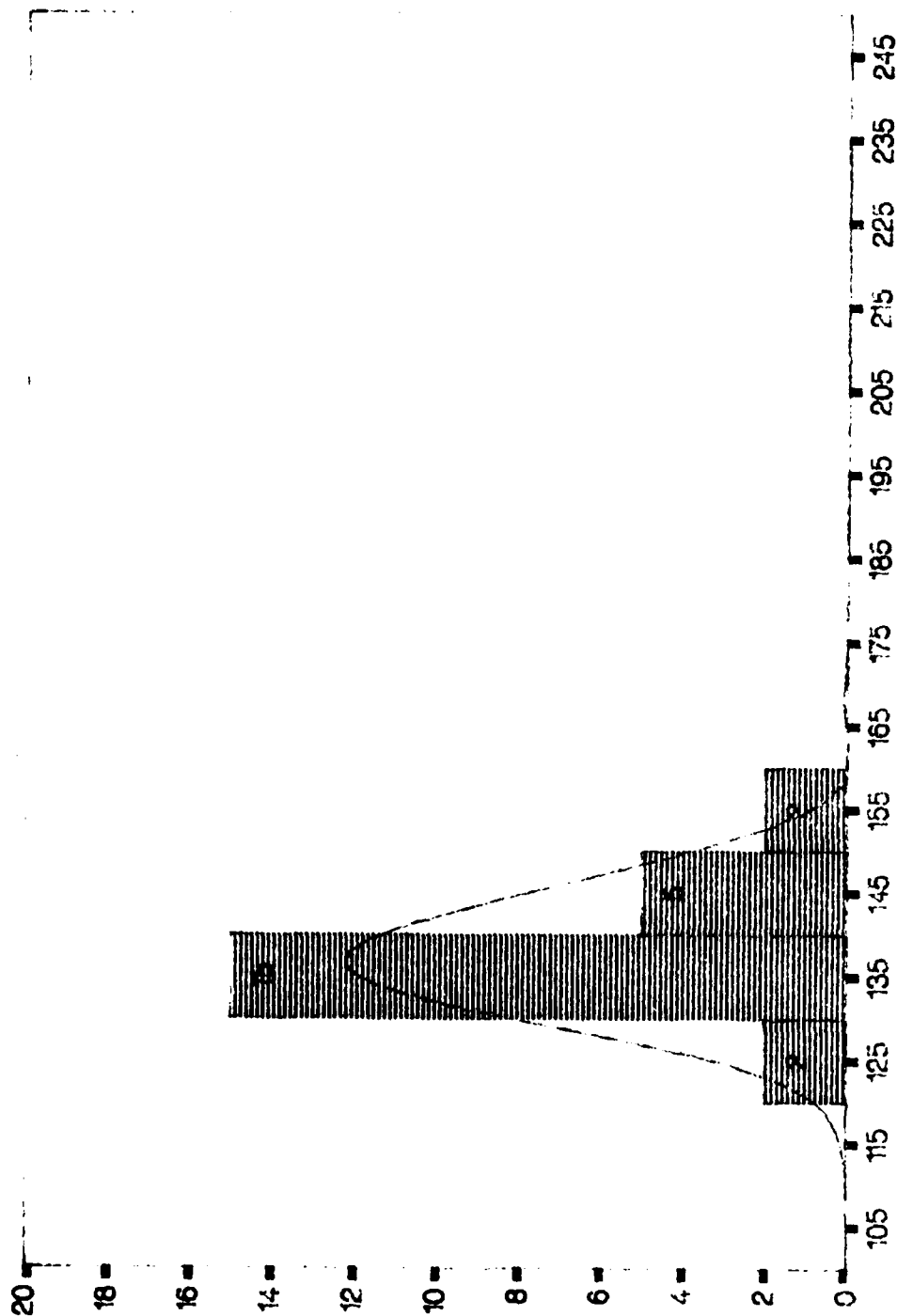
MAXIMUM WIDTH USED (FEET)

FREQUENCY

B-13

MAXIMUM WIDTH USED
225K CFS - 3900 HP

MAXIMUM WIDTH USED (FEET)

FREQUENCY

LEGEND

Std. Dev. = 6.89
Mean = 138
N = 24

B-14
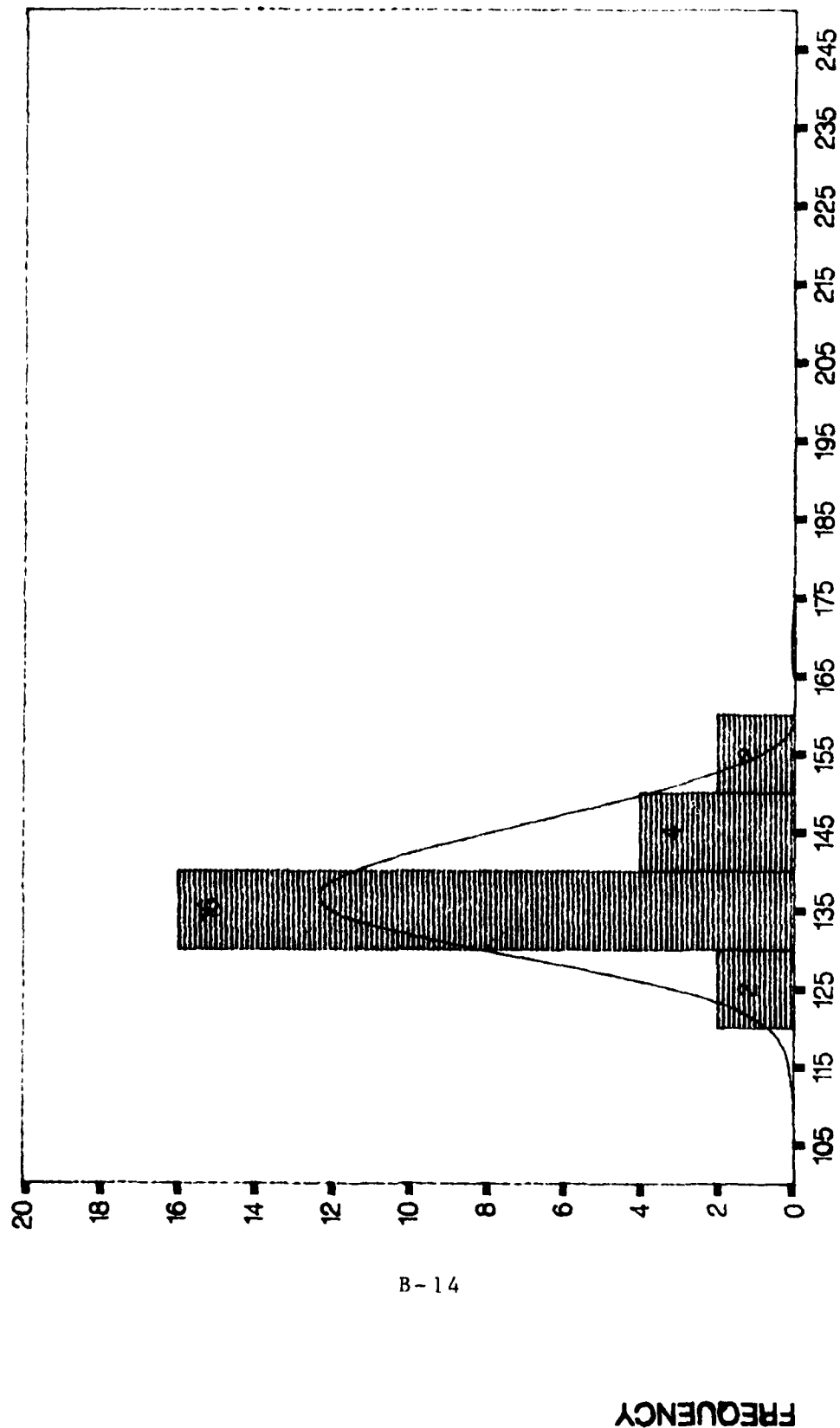
MAXIMUM WIDTH USED
225KCFS - 3900 HP MODIFIED
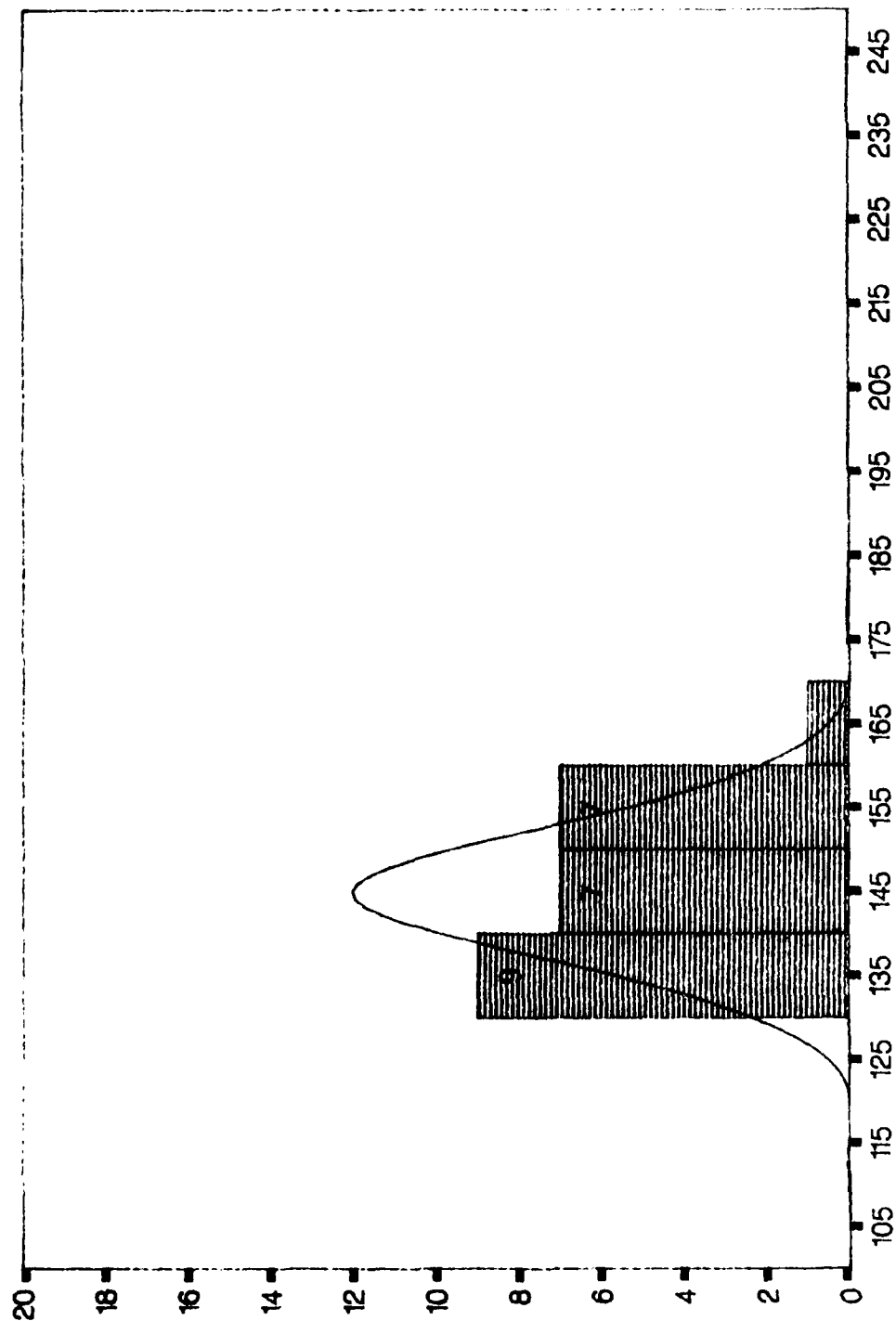
LEGEND

Std Dev. = 7.39
Mean = 145
N = 24

FREQUENCY

MAXIMUM WIDTH USED (FEET)

B-15

Appendix C

Pilot Rating

PILN	HP	DESN	CURNT	REFL	DIFF	DNGR	REAL
9	2	2	2	1	6	4	8
9	1	1	2	1	1	1	8
9	2	1	1	1	1	1	8
9	2	1	2	2	3	3	8
9	1	2	2	2	3	3	8
9	2	2	2	2	1	1	8
9	1	1	2	2	1	1	8
9	2	1	1	2	1	1	8
9	1	1	1	2	1	1	8
9	1	2	2	3	1	1	8
9	2	1	2	3	1	1	8
9	1	1	1	3	1	1	8
9	2	1	1	3	1	1	8
9	1	1	2	3	1	1	8
9	2	2	2	3	1	1	8
9	2	1	1	4	1	1	8
9	1	1	2	4	1	1	8
9	2	2	2	4	1	1	8
9	2	1	2	4	1	1	8
9	1	2	2	4	1	1	8
9	1	1	1	4	1	1	8
10	1	1	1	1	4	2	9
10	2	1	2	1	5	4	9
10	1	2	2	1	2	0	9
10	2	2	2	1	1	0	9
10	1	1	2	1	0	0	9
10	2	1	1	1	1	0	9
10	2	1	2	2	4	2	9
10	1	2	2	2	4	3	9
10	2	2	2	2	2	2	9
10	1	1	2	2	0	2	9
10	2	1	1	2	0	0	9
10	1	1	1	2	0	0	9
10	1	2	2	3	2	2	9
10	2	1	2	3	2	2	9
10	1	1	1	3	2	0	9
10	2	1	1	3	0	0	9
10	1	1	2	3	0	0	9
10	2	2	2	3	3	4	9
10	2	1	1	4	2	2	9
10	1	1	2	4	0	0	9
10	2	2	2	4	2	0	9
10	2	1	2	4	2	0	9
10	1	1	1	4	0	0	9
10	1	2	2	4	2	0	9

NUMBER OF CASES READ =   96   NUMBER OF CASES LISTED =   ..

PILN	HP	DESN	CURNT	REFL	DIFF	CNGR	REAL
5	1	1	1	1	3	2	7
	2	1	2	1	1	10	4
	1	2	2	1	7	5	8
5	2	2	2	1	5	3	8
	1	1	2	1	7	6	6
	2	1	1	1	2	2	7
5	2	1	2	2	4	3	9
	1	2	2	2	7	7	9
5	2	2	2	2	6	4	6
5	1	1	2	2	4	4	8
	2	1	1	2	1	2	8
	1	1	1	2	2	2	8
5	1	2	2	3	6	6	7
	2	1	2	3	5	2	5
	1	1	1	3	2	2	8
	2	1	1	3	2	2	6
	1	1	2	3	6	2	7
	2	2	2	3	4	3	7
	2	1	1	4	3	6	5
	1	1	2	4	6	5	7
5	2	2	2	4	5	6	8
	2	1	2	4	4	4	7
5	1	1	1	4	2	2	6
5	1	2	2	4	6	8	8
4	2	2	2	1	4	4	5
4	1	1	1	1	4	4	5
6	1	2	2	1	4	4	5
4	2	1	2	1	5	7	4
4	1	1	2	1	6	7	4
4	2	1	1	1	4	4	4
4	2	1	2	2	6	5	4
4	1	2	2	2	8	7	4
4	2	2	2	2	4	4	4
4	1	1	2	2	4	4	4
4	2	1	1	2	4	4	4
4	1	2	2	3	4	4	4
4	1	1	1	2	4	4	4
4	2	1	2	3	4	4	4
	1	1	1	3	4	4	4
	2	1	1	3	4	4	4
	2	1	2	3	4	4	4
	2	2	2	3	4	4	4
4	2	1	1	4	4	4	4
4	1	1	2	4	4	4	4
4	1	1	1	4	4	4	4
4	2	1	2	4	4	4	4
4	2	2	2	4	4	4	4
4	1	2	2	4	4	4	4
3	1	1	1	1	2	1	7
3	2	1	2	1	5	5	6
	1	2	2	1	2	3	3

Appendix D

Pilot Comments

Appendix D

Pilot comments - The pilots did have comments on several of the
aspects of the test. Listed below are some of their actual comments or trends in
their comments:

o Tow boat handling - PILN 9 - "The tow (simulator) turned a little
quicker (than an actual tow)." PILN 5 - "It may have answered the rudder a bit
quick and you didn't get quite as much slide after making an extra hard steer."
The primary trend of comment in this area concerned the quickness of tows
response to the rudder.

o Current - PILN 5 "They were pretty much realistic." All the pilots
thought the currents were realistic. They did mention that the simulator picked
up the left hand set closer to the bridge than really occurs. Under real
conditions the tow picks up the left hand set earlier (further from the bridge)
than the simulated scenario.

o Tow's handling going past bridge - PILN 10 - "The tow was easier to
break off the swing span. A real tow would have taken a little longer to break
away after steer."

PILN 9 - "The steering was a little faster."

Again the pilots seemed to think the tow responded a little more quickly than actually occurs.

o Visual scene - PILN 6 - "There needs to be more detail in background down below the bridge. The picture should be clearer and more detailed."

PILN 5 - "The right pier needs to be more clearly defined. The smoke stacks at the power plant above the bridge need to be added. The edge of the tow needs to be a little more defined."

PILN 10 - "There is a move or jerk in the picture as tow approaches the bridge."

The major concerns with the visual scene were the lack of some features that the pilots use to help them navigate such as the smokestack above the bridge as well as the clarity and detail. They did think that what was on the simulator was adequate and were impressed with it. Changes are now in progress that....)

o Changes to make simulator more realistic - PILN 10: "Cleanup the movement in the picture. Should add a rear scene."

PILN 6 - "Add something that lets you know if you hit."

PILN 9 - "Help if I had some way of knowing how far off the right hand pier I was."

The pilots main concern, unamiously, was not having a way of determining how far off the right hand pier they were. They believed this significantly affected their ability to navigate through the bridge.

o   Training - PILN 9 - "It definitely would help."

PILN 6 - "Useful for someone who dosen't know the area. It would help him know what to expect."

o Strategy - All of the pilots held to the right hand pier closer and longer when in the high flow condition.

o Current changes - All pilots noticed change in the magnitude of the current with each different flow pattern.

END
DTIC
7 — 86